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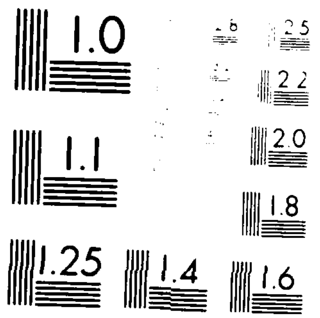
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DEPARTMENT OF THE AIR FORCE

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AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

COST ANALYSIS OF
TURBINE ENGINE WARRANTIES

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In the past, the commercial use of warranties for the purchase of turbine engines has proven cost effective. The use of warranties is now viewed by the Air Force as a viable procurement option for future Air Force turbine engine procurement. The Propulsion System Program Office (SPO) has investigated the use of warranties and recognizes the need for a system that can analyze the life cycle cost of an engine under warranty. This thesis shows the development of a decision support system in a computer model that assesses the turbine engine life cycle cost under warranty. Two versions of the warranty model were developed to provide short and long term warranty analysis and both systems were integrated into the total decision support system designed to assist SPO analysts and contract specialists to evaluate the cost effectiveness of a turbine engine warranty.

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COST ANALYSIS OF TURBINE ENGINE WARRANTIES

A Thesis

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Logistics Management

By

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September 1982

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Captain Michael G. Oliverson

has been accepted by the undersigned on behalf of the faculty of the School of Systems and Logistics in partial fulfillment of the requirements for the degree of

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CHAPTER I

INTRODUCTION

In recent years, the Department of Defense (DoD) has been faced with the problem of procuring high-cost, sophisticated equipment and weapon systems within the limits of an eroding defense dollar and ever tightening budgetary constraints.

Inflation and the cost of high technology have made the difficult problem of maintaining technical and military superiority even more challenging. Efforts by DoD over the past two decades to cut costs and, at the same time, buy what is needed have percipitated the development of many new procurement concepts (13:14,15; 18:2-21; 23). One of particular importance is the concept of Life Cycle Costing (LCC) (18:4-6). This concept developed out of an awareness within DoD that the award of a contract based on the lowest price per item is not necessarily the cheapest. That is, consideration of the research and development (R&D) and production costs alone is not sufficient. Operations, maintenance and support costs that extend over the life of the item must also be included in the cost to realize the complete life cycle cost of that item (3:3; 11:12-21; 18:2-21; 24).

To motivate contractors to embrace this concept and

thereby build a more reliable product, different types of contractual incentives have been used (5:1-5; 11:18-21; 24). Most recently a great deal of interest has been directed toward the use of warranties. Under the warranty concept, an attempt is made to motivate the contractor to provide not only a better product through improved R&D, but also to provide improvements over the life of the product. As a result, the contractor is encouraged to continue to improve the reliability and maintainability after production to increase his profits (6:3; 23:1).

In the past, warranties were used in DoD primarily for the procurement of small off-the-shelf items. Their use, however, is becoming much more important in the acquisition of new complex systems. In the late 1970's, one Slay policy letter (23:1) directed DoD procurement agencies to explore the use of commercial contracting practices and implement them into the acquisition process.

Under this direction, the Deputy for Propulsion, Aeronautical Systems Division (ASD) instituted an indepth study of commercial airline engine acquisition practices. As a result of these studies, several procurement methods were targeted for further study and implementation. Paramount among these was the application of warranties to turbine engine acquisition (15; 25).

However, for ASD to effectively negotiate a warranty, the engine life cycle cost of a system under warranty must be

estimated. Establishing such an estimate should be an integral part of the negotiation process which will provide the necessary information to measure the tradeoffs between the cost and the benefits of a contract assurance. Unfortunately, an instrument capable of producing such cost estimates for turbine engines under warranty was currently not available to the turbine engine acquisition community (15; 25).

Problem Statement

ASD contract specialists are unable to effectively negotiate engine warranties because the information outlining anticipated warranty costs is not readily available. Current operation and support (O&S) cost data do not provide this information. As a result, the Air Force's ability to encourage contractors to improve engine reliability, maintainability and availability is seriously impaired.

Justification

Although the use of warranties for procurement of turbine engines within the Air Force is still in the development stage, they have been used by commercial airlines for many years. Turbine engine procurement under warranty has proven very successful in reducing operation and support costs of the major airlines (12:1-25). In order to provide the Air Force with similar cost savings, in 1978 General Alton D. Slay, Commander, Air Force Systems Command, directed that greater emphasis be placed on commercial practices, specifically the effective use of cost reducing incentives (23:1).

In 1981, Frank C. Carlucci, Deputy Secretary of Defense, re-emphasized the need to improve and update the acquisition process in DoD (10:3). His directive again identified the procurement approaches needed to incentivize contractors to attain reliability and maintainability goals and reduce maintenance, manpower and skill levels. He re-emphasized that the procurement process should include such incentives as guarantees and warranties for improving the reliability of a procurement item.

As a result of these directives, the Air Force is now in the process of developing warranties for turbine engine acquisition. However, as has already been mentioned, to effectively negotiate such warranties a competent decision support system must be developed to supply contract specialists with the specific warranty data they need during source selection negotiation. The purpose of this thesis was to develop such a decision support system.

Objectives and Goals

Primary Objective

To assist the Propulsion System Program Office in the process of effectively negotiating turbine engine warranties, the researchers primary objective was to develop a decision support system that would adequately assess life cycle cost in light of warranty applications. The system had to be transparent to the decision authority and provide only required and relevant information.

Goal One

To develop this system the researchers first determined the information necessary to assess the cost effectiveness of a warranty application. This involved identifying the elements that were needed to effectively assess cost benefits of warranties and developing a logical delivery format for the information and selection of parameters for sensitivity analysis.

Goal Two

The researchers then selected a simulation language which was appropriate for use by ASD/YZ and then constructed a simulation model for assessing the turbine engine life cycle costs under a warranty.

Goal Three

Once the model was verified and validated the researchers employed statistical technology to analyze simulated data and to produce the information Propulsion negotiators and support personnel need to effectively negotiate turbine engine warranties.

CHAPTER II

WARRANTY BACKGROUND

In both the government and commercial sectors of the American economy there is a strong and growing interest in theory, policies and procedures for assuring that products and services conform to the quality and reliability requirements of consumers. This interest was stimulated by a growing awareness of the social and economic costs to the public and to the government of inferior quality (24:16,20). Obviously, product quality and reliability are of major concern to the Department of Defense (DoD) which buys vast quantities of supplies and weapon systems.

This concern for higher quality and reliability, plus the ever increasing constraints on defense spending over the past two decades are two major factors that have influenced DoD to begin developing contract quality and reliability assurances for use in the procurement process (20:3-4). Most important among these assurances is the development and use of product warranties and guarantees (10:166). The basic assumption behind a product warranty or guarantee is that the vendor will be motivated to initially develop a quality product and then continue to improve the maintainability and reliability over its useful life. Thus, the responsibility

for the overall quality of the product remains with the contractor (3:17-19; 17:36-41; 20:25-28; 24).

Currently within DoD procurement there is an intense activity to develop and apply warranties and guarantees. The majority of the development work, however, has focused primarily on the design of contract clauses and restrictions to be included in the contract. The ability to support these clauses with data that includes the tradeoff or breakeven point between benefits gained and costs incurred is presently not a part of the decision process. The breakeven point, however, can be determined by comparing the warranty front end cost with product performance over time (3:15-18; 19:7). As Figure 2-1 illustrates, the front end cost of a warranty is the additional cost to insure improved product performance. The performance improvements include reliability improvements (4:71) that occur over the life of the product such as a reduction in manhours, parts usage rates, shipping and other related expenses. The ability to estimate and compare the life cycle cost of a product with and without a warranty provide the capability to determine the breakeven point. The breakeven estimate is the point in time when the accumulated cost curve due to improved reliability of the product under warranty and the same curve for the non-warranty option are equal (3:18; 19:9).

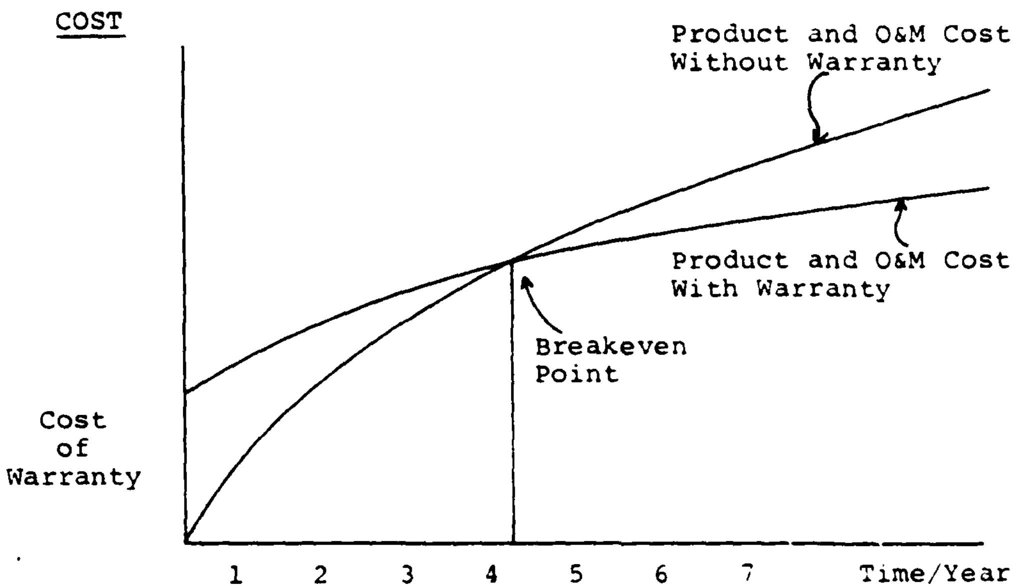


Figure 2-1 Breakeven Point

General Definition of Warranty

Nearly everyone has encountered warranties in some form. They range from the implied warranty received with the purchase of a toaster, to the complex reliability and performance improvement warranties used in buying equipment for the armed forces and commercial industries. To adequately discuss this subject, a uniform base of definitions is needed.

A warranty can be defined as an agreement between the purchaser and seller affording protection against "unidentifiable defects in the supplies or services provided by the seller and to limit the liability of the seller [1:9]." In effect, the warranty is actually the contractual link between

the consumer and vendor both during and after contract completion.

General Types of Assurances

The Uniform Commercial Code (UCC) is used by the United States Government as a guide in warranty application. Two types of warranties exist within the confines of UCC. The first is the implied warranty where the seller is providing "merchantable goods which are to be used for the purpose known to both buyer and seller [1:10]."

In the second, the expressed warranty, the parameters of performance, reliability or other measures are accurately described in some manner of documentation (1:10). It is the expressed warranty with which we concerned ourselves as this is the type currently in use and proposed for future use by the Air Force in acquisition programs.

In addition to warranties, guarantees are also used to provide similar assurances. In general usage, the terms warranty and guarantee may be considered as synonymous. However, for the purposes of this thesis, the following operational definitions were established.

Warranty

A warranty is intended to apply to hardware on a per unit basis. An example would be a specific engine by serial number and the parts on that engine such as fans, rotor and frames. The warranty is usually characterized by negative incentives such as a dollar penalty for less than agreed to

life lengths (2:2-26).

Because of its diversity, the expressed warranty is most commonly used warranty in DoD procurement. A wide variety of options may be incorporated within this warranty. These may range from maximum operation costs of a system over a period of time to the reliability of a specific part.

One of the first and most basic expressed warranty options used in government procurement was the Correction of Deficiency Clause. This clause was and is used as a bridge between the implied and the expressed warranty and is one of the original attempts at holding the contractor responsible for his product. This option requires the contractor to correct or repair defects discovered in items delivered to the government under that contract. The general thrust is to insure that design, workmanship and material quality are maintained at an acceptable level (3:31; 14).

As expressed warranty application techniques began to mature and expand within the government, other options were used. Three of the most commonly applied clauses or options within the expressed warranty are the standard clause, the ultimate life clause and the service clause.

The standard clause, commonly referred to as the "failure free warranty," is designed to provide protection for the consumer against defects in material, workmanship and design (20:2-26). The level of protection is expressly defined in the contract and includes the reparation require-

ments.

The life limited clause, known as the ultimate life warranty, places the burden of designing parts to last a specified lifetime on the contractor. The strength of this warranty is tied to the penalty for less than agreed life limits experienced by the parts (20:2-26).

The final option discussed here is the service clause. Just as the design and manufacture of a product requires quality assurances, so does the rework or maintenance of that product. The service warranty is simply the assurance by the maintenance or repair organization that the work done is of the expected and agreed to quality (20:2-26).

Guarantee

Along with the maturation of expressed warranties, guarantees also grew to be an important part of contractor assurances. However, as opposed to warranty, a guarantee applies to the aggregate population. This type of assurance applies to the shop visit rate or other levels of performance for the entire engine fleet. The guarantee may have either negative or positive incentives attached. These incentives may be a reward for better performance and a penalty for poor performance. Two of the more generally used options within a guarantee are the maximum parts cost guarantee and the reliability guarantee (2:2-26).

Within the context of the maximum parts cost guarantee, the contractor predetermines the operation and main-

tenance costs of an item and guarantees that these costs will not be exceeded. This guarantee takes into account the cost of replacing failed parts and includes positive incentives for lower per hour costs (2:2-26).

Whereas the maximum parts cost guarantee is an assurance that certain costs will not be exceeded, the reliability guarantee is an assurance of item reliability. The reliability of the item is measured by the average time or mean time between failures (MTBF). This guarantee is designed to place a requirement for an expected level of reliability, as measured by the MTBF, on the contractor.

Warranty and Guarantee Application

Over the past two decades DoD has developed and used warranties and guarantees for procurement. However, the use of the full range of contractual assurances has not been applied as rapidly as compared to civilian purchasers. This is particularly true for the purchase of major complex weapon systems, including aircraft turbine engines (8:4-6; 12:4,26).

Commercial Airline Contract Assurances

For a number of years commercial airlines have enjoyed the benefits of contractor assurances including warranties and guarantees for turbine engines. They have developed methods and organizations to both negotiate and administer the many aspects of these assurances. One major development is the concept of complete or total package procurement (TPP) (8:36).

Under this concept the airlines contract for the

engine and all supporting portions of the propulsion system such as technical data, support equipment and other assorted items as a complete package. There is one cost for the engine, and implicit in the cost is the knowledge that the engine will be provided to specification with all necessary equipment and contract assurances. The emphasis of TPP is that a single price is proposed, and included in that price are all necessary assurances and equipment. None of the items are contracted for separately (12:4,25-36).

Civilian vs Military Engine Procurement

DoD is not in a position to include assurances in its procurement process as extensive as those included in the TPP. Obviously, mission requirements put the government at a disadvantage when trying to apply the more inclusive type warranties (12:3-5; 16:45-67). Two major disadvantages for DoD when negotiating a turbine engine warranty include the inability of the contractor to predict engine usage parameters and the restriction placed on DoD negotiators putting them in a less competitive position (22).

Engine Usage (Civilian vs Military)

An estimate of turbine engine reliability in the commercial airlines is easily determined and monitored. In commercial flying rarely are normal engine operating limitations pressed or exceeded. The operating environment of the engine is steady and predictable, making it comparatively simple for the manufacturer to study the operation and main-

tenance procedures and thus specify the warranty parameters (12:4,26-28).

In contrast, Air Force contractors have difficulty in closely predicting the scale and variety of parameters of an engine when used in a fighter type aircraft. Because of the Air Force mission, this engine has a much higher probability of pressing or exceeding normal operating limitations thus making estimates of engine reliability rates difficult. This problem has made contractors skeptical and in most cases made both the military and the contractor unwilling to consider a warranty (15).

Procurement Methods (Civilian vs Military)

The second major advantage airlines have in buying an engine under warranty involves the procurement methods they may use. The commercial airlines enter all negotiations in the true spirit of free enterprise. They may bargain and barter with the supplier and in effect auction the price down. In its purest sense this is true competition (8:1-10; 12:5-17).

The Air Force, on the other hand, is restricted to a less than competitive position by the Defense Acquistion Regulation (DAR) (22). This document restricts the Air Force from bartering or auctioning down the price of a contract, and overall, limits the latitude the Air Force has in the entire negotiation process. These restrictions have historically made the up front cost of a warranty too expensive.

For these two reasons, warranties and similar type

assurances were not used by the Air Force for many years. However, in the late 1960's and through the 1970's, the defense dollar began to shrink. With a tightening defense budget, DoD began to look more closely at its acquisition process in order to meet its needs. The Air Force and other defense organizations began to realize that operations costs were as much or more of the total life cycle cost of the item as were the acquisition costs. Studies proliferated in the areas of cost analysis, life cycle cost and cost/benefit tradeoffs with the idea of applying contractor assurances wherever possible. One result of these studies was the recognition of the commercial success of warranty application for turbine engine procurement (25). The possibility of using contractor assurances such as warranties and guarantees began to appear to be a viable option for acquiring the high cost turbine engine technology needed to meet the needs of the Air Force.

Development of ASD Contract Assurances

In December 1978, General Alton D. Slay, Commander of Air Force Systems Command, directed that "more effective... cost incentives" be used in acquisition of weapon systems (23:1). This directive was interpreted, in part, to include the use of warranties for all major system and subsystem procurement (15). General Slay's policy letter initiated many acquisition concept studies by Air Force organizations that were involved with developing and buying weapon systems.

Included among these studies were those done by the Deputy for Propulsion of the Aeronautical Systems Division for turbine engine warranty application (15).

In addition to the Slay directive, emphasis for the need of contractor assurances was provided by the Carlucci initiatives in 1981. Initiative number 16 re-emphasizes the need for "contractor incentives to improve reliability and support [7:3]." This was interpreted to be high level reinforcement and administrative encouragement of the action already taken by the turbine engine acquisition organization (15). The contractor assurances under development were specifically directed at improving system reliability and reducing support costs. Both the Carlucci initiatives and the Slay policy letter have provided the direction for developing innovative and cost reducing procurement methods. The emphasis in both directives is on increasing system reliability and support with heightened contractor involvement.

Following the Slay and Carlucci directives the interest in developing contractor assurances such as warranties grew rapidly within ASD. They realized, however, that they knew very little about the subject; and, as a result, several studies were conducted. These studies included a review of contract assurances used by Delta, Eastern and United Airlines and those used by turbine engine manufacturers including General Electric, Pratt and Whitney and Rolls Royce. This initial research was a major step forward in developing a

commercial type warranty/guarantee package. It was important because it provided ASD with an indepth view of the manufacturers responsibility for the life cycle performance of his product and how this responsibility was carried forward by the use of warranties. The interest in engine warranties in the Air Force has continued to increase with the development of new methods of warranty/guarantee application and the modification of existing commercial contractor assurances (25).

Warranty and Guarantee Benefits

The airlines have experienced a great deal of success with turbine engine warranties. Through their use, engine reliability has increased thru providing the airlines with savings over the life of the engine. The airlines found that as the cost of a warranty increased so did the reliability of the engine and that over time this higher reliability resulted in savings (12:4,26-37).

With the success the commercial airlines have had with warranties and guarantees, the question still remains as to whether or not these types of assurances can be developed for use by ASD; and, if so, what benefits will be gained. In response to these questions, it was proposed that contract assurances similar to those used by the airlines could be developed and that a contract package, including both warranties and guarantees, would provide three general improvements to the Air Force turbine engine acquisition program (12:26-37;

15; 26).

First, it would improve the reliability of the product. Based upon the reliability improvements realized by the airlines, if similar type assurances were developed and properly negotiated, product reliability should improve at a savings to the Air Force.

Second, a warranty would fix the cost of ownership. This means it would specifically outline the vendors responsibility for product costs during and after production and place ceilings on the different life cycle costs of the engine. These cost ceilings would apply during the early stages of procurement when the vendor is supplying training and equipment while the government is establishing self sufficiency. It would also include a ceiling on government operation costs and, most important, place a ceiling on the cost of spare parts to support the operation of the system (12:26-37; 15; 25).

Finally, warranties would reduce the cost of engine ownership. Just as good design leads to a good product, continuing design work combined with historical operating data could provide further improvement. Through design improvements overall system life and reliability would increase, and the engine shop visit rate would decrease providing more savings to the government (12:26-37; 15; 25).

Hopefully, this brief look at the general functions of a warranty or guarantee in turbine engine procurement has

provided a basic understanding of how a warranty would be applied within the turbine engine acquisition community, and what benefits would be obtained. To understand the environment in which warranties and guarantees are negotiated, it will now be necessary to look at the acquisition cycle for a system, the process of contract negotiations within the cycle, and the time phasing for applying a warranty.

System Acquisition Cycle

Illustrated in Figure 2-2 is the four-phase system acquisition process. It includes the conceptual, validation and demonstration, full scale engineering development, and production and deployment phases (21:17-30).

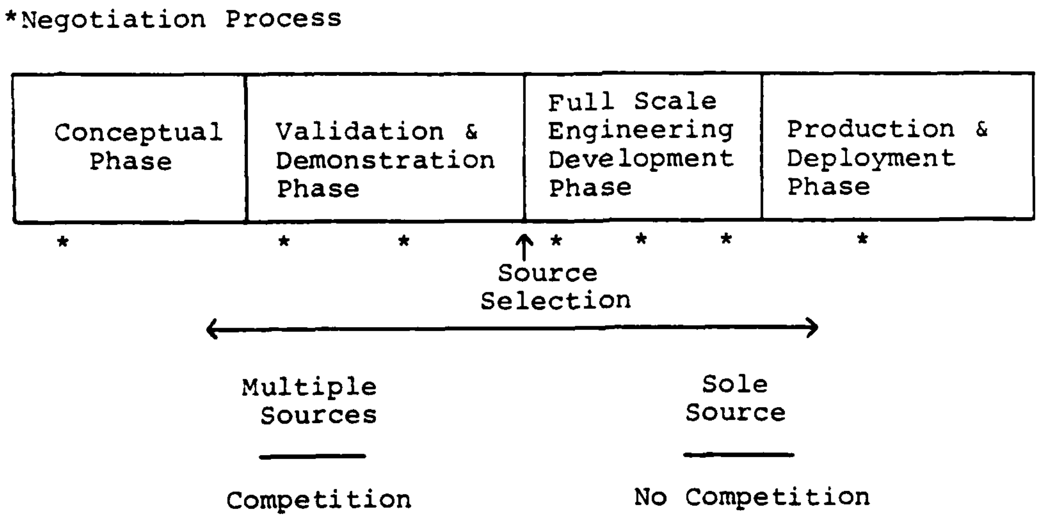


Figure 2-2 Four-Phase System Acquisition Process

Within the first phase, the need for a new system is identified. Initial research is done to define the system

that will best meet the need which is followed by the definition of the base line requirements for such a system.

The acquisition process then moves into the validation and demonstration phase. Those systems that have met the base line requirements are further studied. Within this phase, system requirements are more closely identified and defined. This narrows the field to perhaps two or three contractors whose designs meet the specifications. Prototypes may be developed to demonstrate the validity of the particular design for meeting the government's need. At the end of this phase, one design is selected for full scale development (10:574).

In the full scale engineering development phase, the selected design is developed in even more detail then in previous phases. Also, specifics for further system development and construction are worked out, and the production contracts are formalized (10:575). With the system in detail form and the contract for production finalized, the system then moves into the final phase (10:575).

Just as it states, within the production and deployment phase, the new system goes into production and is distributed to the user (10:575). Also throughout the phase, follow-on production may be contracted and engineering improvements may continue during the production and use of the product.

Contract negotiations occur during all four phases of the acquisition process (10:562). From the conceptual phase,

where many proposals may be considered, to the development and production phases of the final system, where only one proposal is considered, contracts may be negotiated and renegotiated as the system develops or as changes occur. The nature of this negotiation process is discussed in the next section.

The Negotiation Process

When the need for a new weapon system is identified and initial acquisition funds are allocated, the government prepares a Request for Proposal and submits this document to interested contractors. The contractors respond to the request by designing a system that meets government specifications and submit their proposal to the government. These proposals are reviewed by government contract negotiators and technical support personnel; and the source selection process begins.

The technical support team composed of engineers, logisticians, budgeteers and managers evaluate each contractor proposal. For an initial or intermediate contract, in the conceptual or validation phase, members of the team interact with contractors to clarify any differences between the contractors' proposal and government specifications. Each proposal is rated according to how well it meets the government specifications. Those that are close to the anticipated cost, and can meet the system requirements, enter the negotiation and bargaining phase of the negotiation process (25).

There are four main groups of people involved in the negotiation and bargaining process. They are: the government negotiators, the contractor negotiators, the government support team, and the contractor support team (25). The bargaining process in which these people are involved can be considered a serious complicated game of proposals and counter proposals. In the bargaining game, only the negotiators are allowed to talk to each other. These people are familiar with the rules and strategy of the game but not with the technical specifics of the product. It is the responsibility of each of the support groups to continually provide the technical information needed for effective negotiation (22:148).

Hopefully, through the bargaining process, a proposal will be made that is acceptable to both the government and the contractor. That proposal then becomes an agreement between the government and contractor. The final authority, however, for source selection decision is that person designated by law or policy to be the final decision point. This person will make, on recommendation of the proposal evaluation and agreement, a decision on the winning contract (22:149).

This summary of the negotiation process indicates the general intent of the negotiation sequence. It should be clear that for a warranty evaluation the evaluators are in fact the support group. They are the logisticians, contract buyers and program controllers who are most familiar with the process itself. However, it is the negotiator alone

who is aware of the rules and must develop the overall negotiation process.

Warranty Application

Having looked at the negotiation process itself, the next question is when is the warranty negotiation started during a system life cycle? The simple answer to this question is that the warranty can be applied either early or late in the acquisition process (16:4-5). A look at each, with their benefits and drawbacks is necessary.

As an example of early application, we assume that the acquisition process is at the point when the government is considering several contracts and is in a fairly good negotiating position. Most likely warranty negotiation would occur during source selection, where all the contract proposals are under consideration. With several contractors bidding against each other, the government would have the advantage of obtaining a relatively good price under acceptable conditions. The only serious drawback would be that it is early in the program and engine specifications are not well known. This makes actual price level setting more difficult.

If a warranty is negotiated during the development and production phases, it is considered a late application. The main advantage of such an application would be that the hardware would have already been developed and firm data would be available on failures and reliability. However, a strong disadvantage to such an application is that only one

contractor would be available to negotiate the contract, placing the government in a relatively poor negotiating position (15; 25).

Once the decision of time phasing has been made, the next step is to provide the information required for actual negotiation of a warranty. The entire information base can be constructed from three pieces of information. The first is the total life cycle cost without the additional costs of warranty. The second is the life cycle cost with a warranty option and the third is a comparative analysis of each, thus providing the breakeven point (15; 25). The breakeven point, as previously defined, is the point in time when the cost/benefits of the warranty and non-warranty option are equal. Therefore, by knowing the two LCC estimates and the breakeven point it is possible to determine whether a warranty will provide protection for the government or be a waste of federal funds. Simply stated, if the breakeven point occurs before the end of the systems life cycle, the application will be favorable to the government.

The data used to analyze the costs and benefits of a warranty are provided by both the government and the contractor. Contractor supplied data have been the backbone of government acquisition work for a number of years (15). The development work done by the contractor is extensive and specifically directed towards providing data in a form necessary for cost analysis. It is assumed that the data supplied in a proposal

will not be biased as the competition and contractual factors of a negotiation tend to keep the contractor within bounds to protect himself and also gain the contract.

Under the assumption that all data necessary are available from the contractor, there exists a need to assimilate that data into information to support the decision process. ASD has developed a large data base for the application of turbine engine warranties and guarantees without fully assessing LCC and breakeven points. Remedying this serious deficiency in the warranty application process was the target of this thesis. The researchers attempted to develop and implement a decision support system that assesses the warranty breakeven point and provides the information necessary to negotiate a turbine engine warranty.

CHAPTER III

METHODOLOGY

This chapter illustrates, in detail, the route or methodology used to accomplish the objective and goals of this research effort. It outlines a three stage process which allowed the researchers to produce a decision support system (DSS) that would assist in the evaluation of engine warranty options.

The first stage involved working with the ASD Propulsion SPO to conceptualize the O&S system and to identify the elements that define and bound the system. During the second stage an experimental design was developed, which required the creation of a simulation model of the O&S system, verification and validation of the computer model, and sensitivity analysis concerning how various model parameters effect O&S system behavior. The final stage involved the integration of the simulation model into the decision support system (DSS).

Conceptualization

Engine Operations and Support System

As previously indicated, the purpose of this research effort is to provide the Propulsion Deputate with a tool for evaluating the cost tradeoffs between warranty and non-war-

ranty options for engine procurement. To meet this objective, the researchers needed to gain a thorough understanding of the components of the O&S system as well as understand their interactions.

System Boundaries and Definition. To gain the insight and background necessary to effectively analyze and model an engine O&S system, the researchers consulted with logisticians and contracting personnel (15; 25) in ASD/YZ. Their experience and expertise with the O&S environment as well as their previous involvement with engine LCC models, provided the basic framework for an analysis of the system.

Initial studies indicated that the engine O&S system could be modeled as the interaction of two major subsystems, engine operations and engine support, as shown in Figure 3-1.

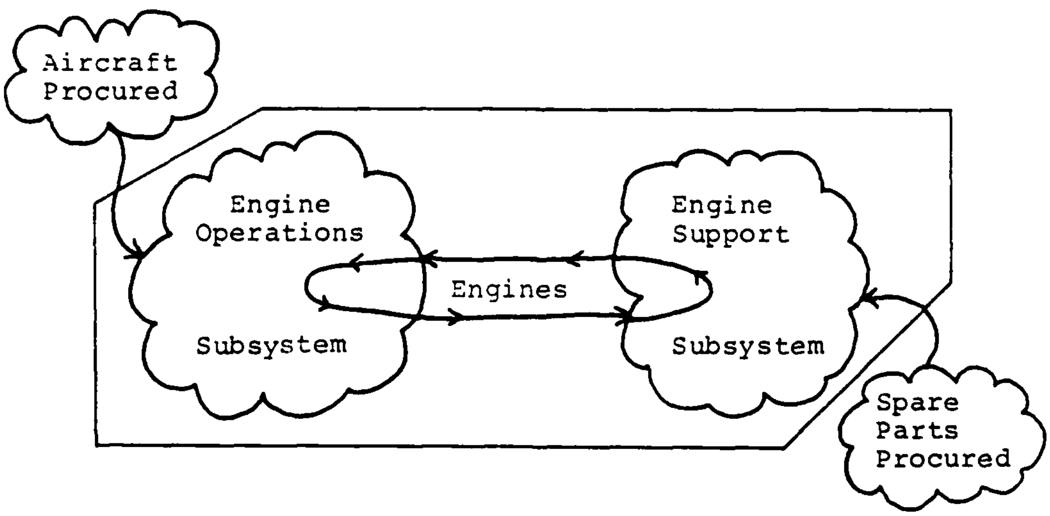


Figure 3-1 Engine O&S System

This division requires an engine be in use within the engine operations subsystem or in some state of repair within the engine support subsystem. Procurement events for such items as aircraft, engine, LRUs and SRUs are considered elements of the external environment.

Engine operations involve the day to day routine of deploying and flying aircraft. When an engine fails within the operation subsystem, it enters the support subsystem where it is repaired and returned to operation. These two subsystems are further broken down into interrelated processes which identify more specifically the system boundary and provides a flow for engine operation and support activities.

Engine Operation. The activities within the engine operation subsystem are shown in Figure 3-2.

Aircraft are procured outside the bounds of the O&S system and enter the operations subsystem following a predetermined deployment schedule. When aircraft become operational, sets of additional engine support equipment are also deployed based on the number of aircraft at each base.

As each engine first enters the inventory it is scheduled for regular inspections determined by engine operating time. An inspection may also occur because of an engine malfunction. Following each inspection the engine either remains in operation or enters the support subsystem for repair.

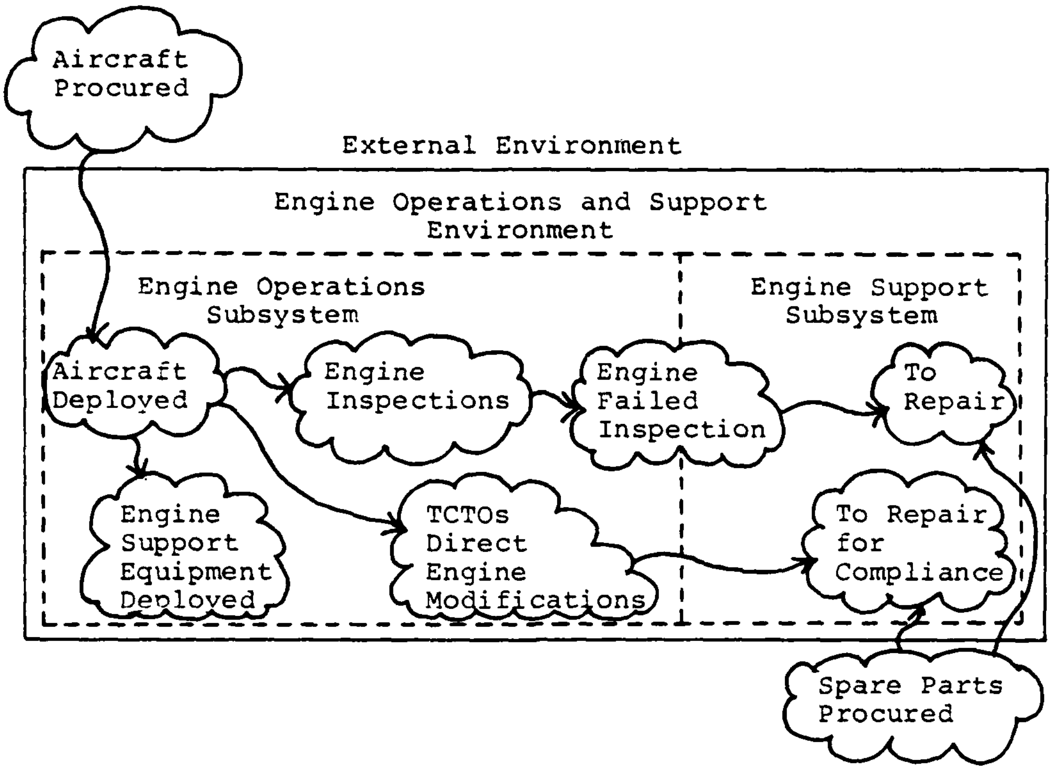


Figure 3-2 Engine Operations Subsystem

Engine improvement modifications also occur throughout the engine's life cycle. These modifications are directed by TCTOs to be completed within a certain time period. To meet the timing criteria, modifications are completed when an engine is down for repair; otherwise, the engine is removed specifically for modification. All TCTO engine modifications are accomplished in the engine support subsystem.

The engine operation subsystem discussed here identifies the routine engine activities. However, when an engine fails an inspection, or is removed for a modification,

it then enters the engine support subsystem for repair or compliance to the TCTO.

Engine Support. The maintenance activities within the support subsystem are a function of the failure probabilities of all engine components. The failure probability for each component is determined jointly by the manufacturer and the government and is used within the engine support subsystem to project engine failure and the associated maintenance activities and costs for repair. Engine repair within the support subsystem involves three distinct repair processes: the repair of line replaceable units (LRUs); the repair of shop replaceable units (SRUs); and major engine damage repair as shown in Figure 3-3.

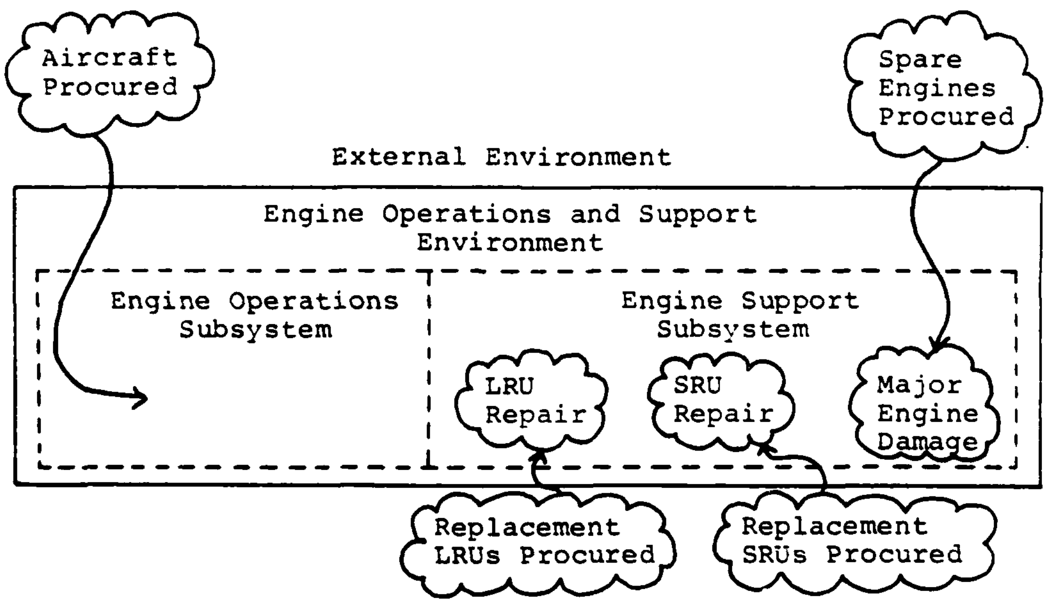


Figure 3-3 Engine Support Subsystem

Line Replaceable Units (LRUs). An LRU is described as a remove and replace item. It is an external engine component that is easily accessed by maintenance personnel and can be replaced on the flightline without removing the engine from the aircraft. Examples of LRUs on the F101 engine are shown in Table 3-1 and Figure 3-4 illustrates the maintenance flow for a failed LRU.

TABLE 3-1

LRUs (F101 Engine)
Engine Control Unit
Fuel Unit
Hydraulic Pump
Oil Pump
Anti-Icing
Alternator

Two conditions may exist when an LRU failure results in an inspection of an engine. Either the engine failure is initially determined as an LRU malfunction and the engine is repaired on the flightline, or the cause of the engine failure is unknown and the engine is removed for teardown and repair. In the latter case, LRU failure is determined after teardown. The LRU is removed and replaced, and the repaired engine is sent to the spares engine pool. In both circumstances, the defective LRU is sent to depot for repair. If repaired, the unit is returned to the spares pool. If condemned, a replacement unit is procured from outside the O&S

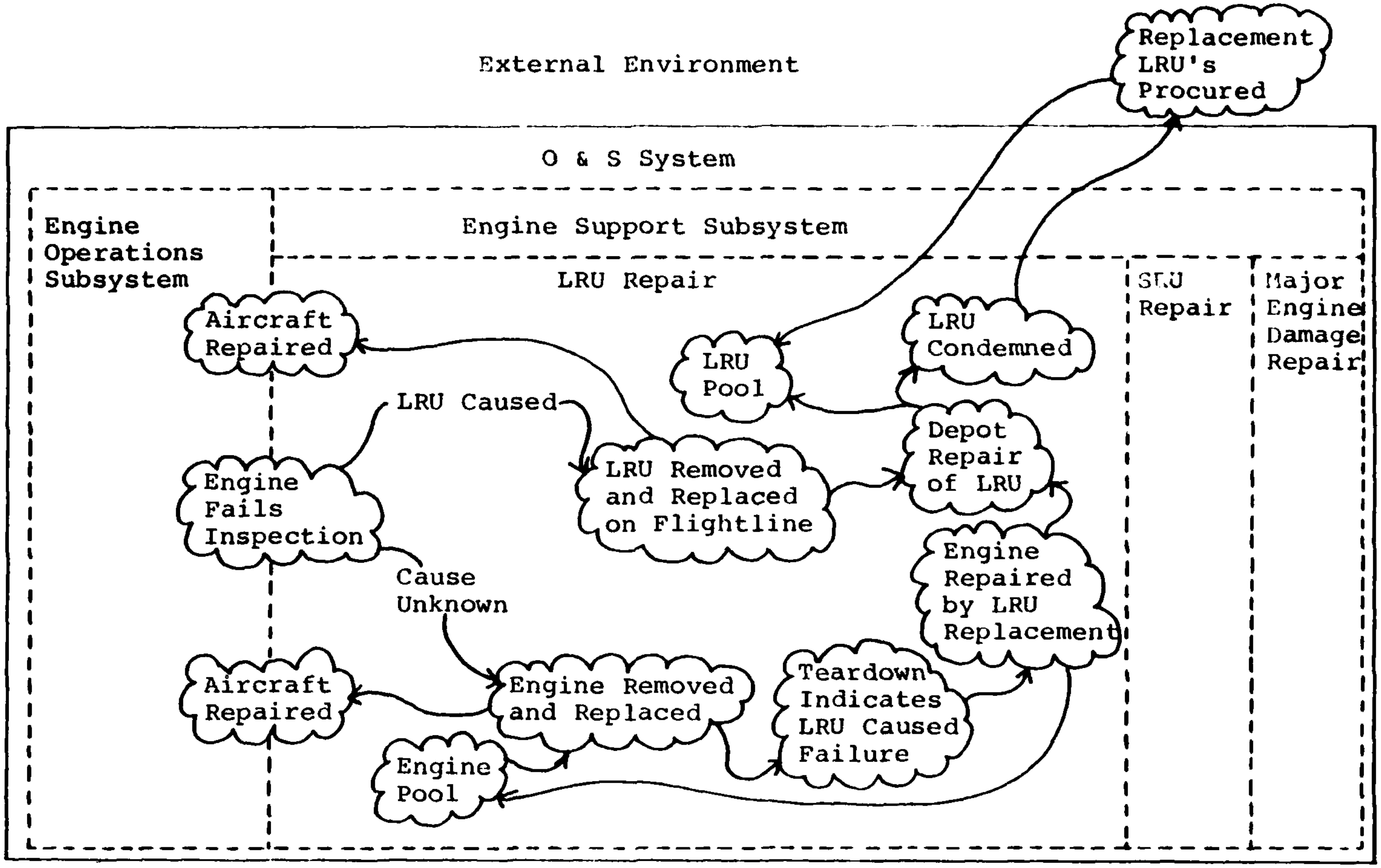


Figure 3-4 LRU Repair

system and enters the engine support subsystem through the spares pool.

Shop Replaceable Units (SRUs). In contrast to LRUs which can be removed and replaced on the flightline, SRUs are major internal engine components that require engine teardown for replacement. Table 3-2 is a listing of some of the SRUs in the F101 engine. The maintenance cycle for an SRU is shown in Figure 3-5.

TABLE 3-2

SRUs (F101 Engine)

Front Frame
Engine Inlet Gearbox
Accessory Gearbox
Combustor
Turbine Frame
Augmenter
Exhaust Nozzle

As illustrated, if the reason for failure is unknown the engine is removed for teardown. If it is determined that an SRU has caused the malfunction, the unit is removed and replaced and the engine is returned to the spare engine pool.

The damaged SRU is sent to the intermediate base shop or depot for repair. Whether the unit is repaired at the intermediate or depot level is determined by one or more of three basic criteria. They include, the repair time,

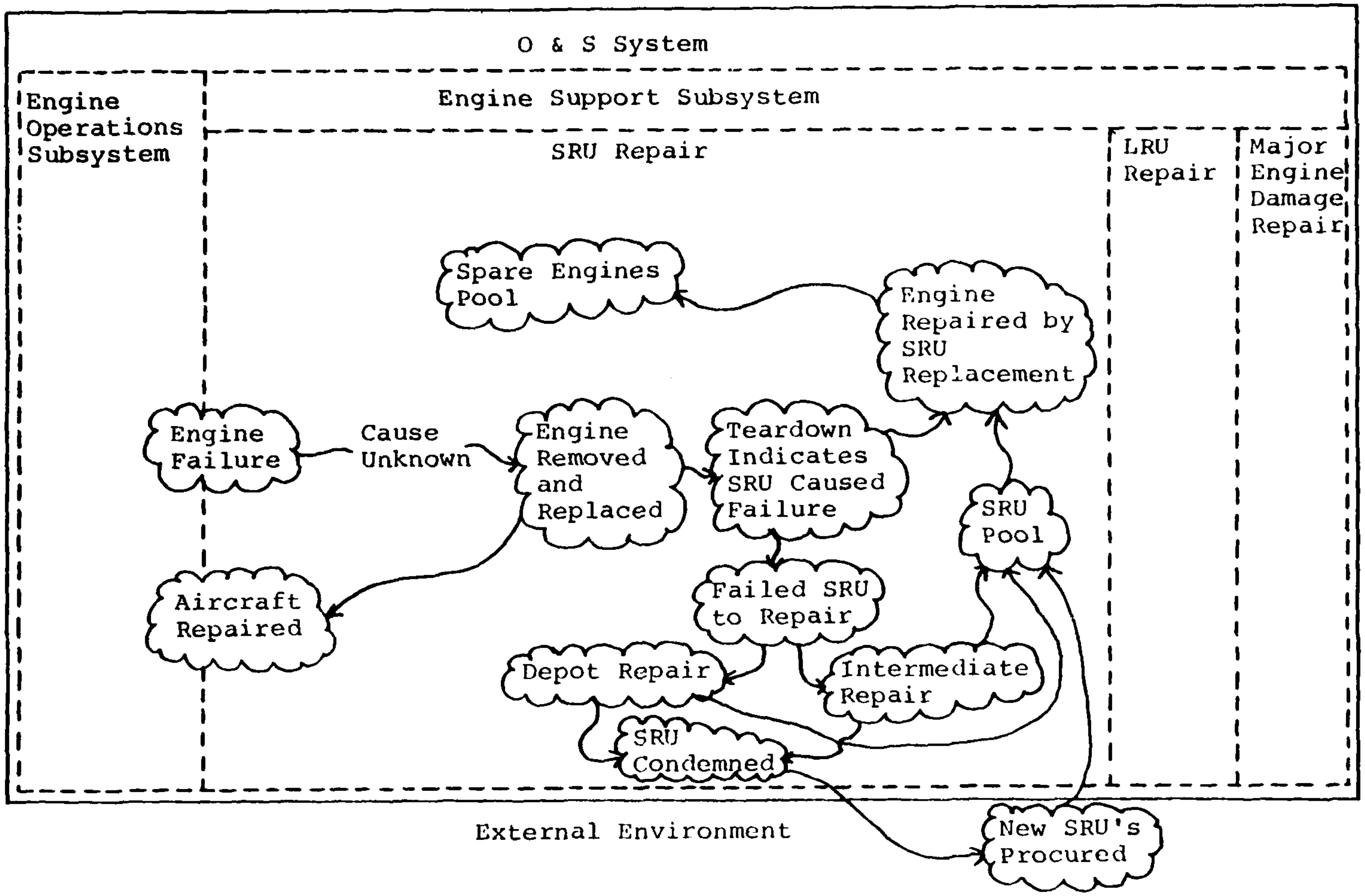


Figure 3-5 SRU Repair

the workload at each level, and the type of support equipment necessary for repair. For example, the repair of a particular SRU may require a heavy press or specialized equipment. The intermediate repair shop at the base level may not have the specialized equipment or is backed up by a heavy workload. Under these circumstances, the unit would be sent to depot for repair. Also, a depot repair would result if process manhours are too high for the intermediate shop. SRUs repaired at both levels are returned to the spares pool.

If a damaged SRU is not reparable at either level it is condemned and a new unit is procured. As with the LRUs, SRUs are also procured from outside the O&S system and enter the engine support subsystem through the SRU spares pool.

While both LRU and SRUs are removed and replaced at the base level, LRUs are repaired at the depot level and SRU repair can be made at either the intermediate base or depot level. The final area of repair is for major engine damage.

Major Engine Damage. Major damage is defined as damage not reparable by LRU or SRU replacement. Shown in Figure 3-6, when major engine damage occurs, the engine is removed and set to depot for repair. The repaired engine is then returned to the engine spares pool.

Engine replacements required to maintain the desired spares level are procured in the initial engine pur-

chase agreement. The engine spares pool is maintained by that initial procurement.

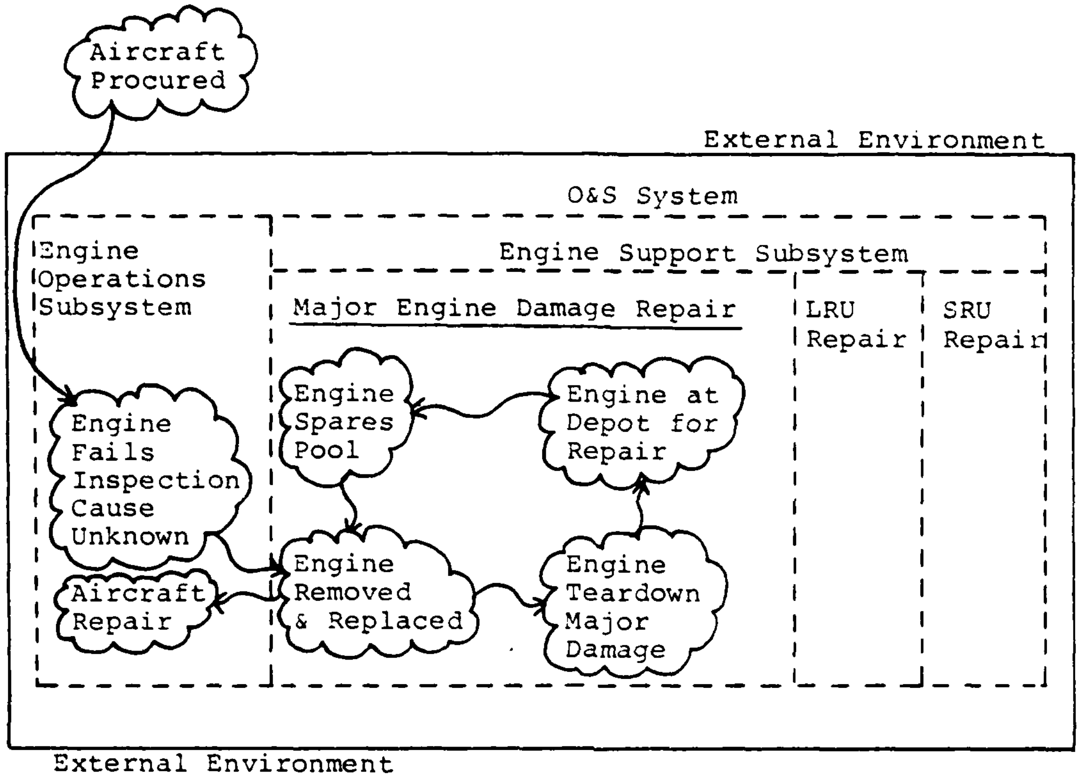


Figure 3-6 Major Engine Damage Repair

The repair of major engine damage is the final area of repair within the engine support subsystem. The discussion of the activities within this major repair area, as well as those within the LRU and SRU repair areas, has defined the boundaries and maintenance flow of the engine support subsystem. The complete O&S system including both the engine operations subsystem and the engine support subsystem is shown in Figure 3-7.

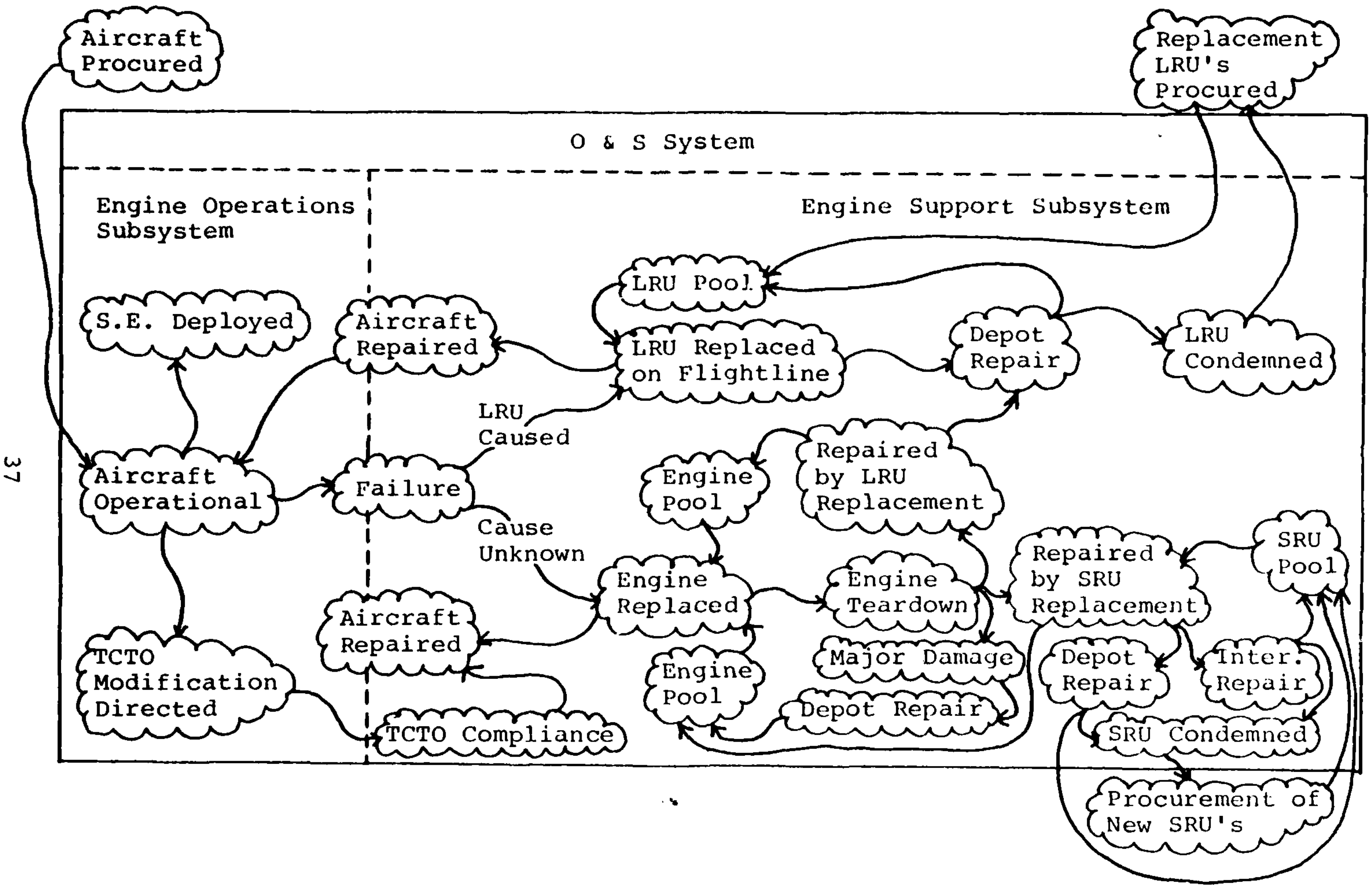


Figure 3-7 Engine Operation and Support System

System Parameters. Once the major activities were defined and the overall boundaries of the engine O&S system were established, the input parameters that would have an impact upon those activities as well as output measures of system performance had to be identified.

Input Parameters. YZ logisticians (15; 25) were consulted to help the researchers nominate the O&S system input parameters associated with the activities within the two O&S subsystems. Parameters were selected whose values are negotiable. A small number of those parameters are referred to as policy parameters because system analysts expected that they would have the greatest impact on system behavior. There were a total of five policy parameters identified by Propulsion analysts.

The parameter values for all input parameters are estimated by both the contractor and government analysts to provide as close as possible a homomorphic representation of the real world engine O&S environment. A specific level of output is derived as a result of using these values in a simulation. This output is referred to as the system measure of performance.

System Performance Measure. The most important measure of performance produced by the engine O&S model is the total cost of operations and repair accumulated over time. It is the measure used to determine if the modeled system is indeed imulating the real world. These final cost figures

are also the output data points used by YZ engine analysts and negotiators to determine the cost effectiveness of a particular warranty proposal.

In the preceding conceptual study, the system boundaries were defined and the major components and processes that constitute the daily activities of the O&S system were determined. The input parameters associated with the activities and the output or system measure of performance were also identified to complete the conceptual phase of the O&S system research process.

This research provided a conceptual view of the O&S environment and enabled the researchers to specifically identify the system components and parameters, and define the system boundaries that were to be modeled. The next phase of the research effort involved transforming this conceptualization of the O&S system into a precise mathematicological model that could be computerized and would provide the data used during the experimental design phase of the research. This design involved model validation and verification as well as the analysis of system sensitivity to various changes in policy parameter levels. The experimental design is illustrated in Figure 3-8.

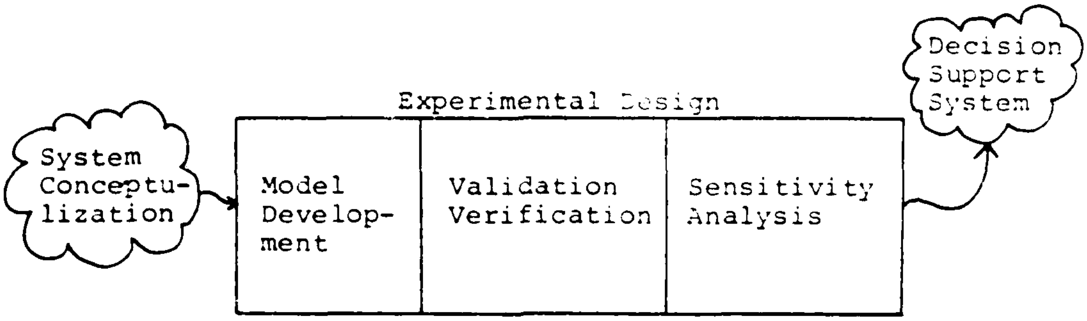


Figure 3-8 Experimental Design

Experimental Design

The experimental design of any simulation analysis specifies the strategy for gaining information, via a simulation model, about a real world system. For the purpose of this study, the strategy for acquiring an understanding of the O&S system under warranty included a three step process.

First the O&S computer model was constructed. It was then verified and validated to develop user confidence. In the third step the model was tested for sensitivity to a change of specific parameter values which involved a screening and analysis of the five policy parameters to determine which had the greatest impact on the O&S system behavior (15).

Model Development

Event logic is the bridge between the system conceptualization and a computer model. It ties the events together in a logical process that simulates as close as possible the real world system. This section provides the model overview

and limitations, and discusses the event logic selected to simulate the engine O&S system.

Model Overview. A brief overview of the simulation model is provided in the following section. A discrete event simulation is used to simulate engine operations and support for a peace time scenerio at five bases. This type of event simulation is most useful to engine analysts because it identifies each occurrence of an event within the system through time, thus enabling the user to track the data associated with each event. Specifically, the simulation is designed to assess and accumulate the cost for engine inspections at the base level and the cost for engine repair at the flightline, base intermediate shop and depot levels.

The basic model is also designed to provide YZ analysts with a variety of output information. The model is versatile in this respect in that it provides the user with the ability to vary the simulation period as well as determine the quantity of output data needed for warranty analysis. The internal integrity of the model does not change with different output versions but allows the analyst to choose the output information most appropriate for a warranty analysis. For the purpose of this study, two versions of model output were developed.

The first version, SHORT.3, was designed to provide a breakout of cost information for the warranty period. As the simulation tracks each engine component in the O&S system,

the accounting process accumulates and provides a monthly breakout of unit failure and repair costs. With this version analysts are able to closely follow individual unit costs and compare these costs to the anticipated contractor costs under warranty.

In the second version, WARR.3, the output of monthly data is suppressed and accumulated to provide only the year and total cost over a 20 year simulation period. YZ considers 20 years to be the normal life cycle of a system. This year end data is used to analize the cost effectiveness of a warranty over the anticipated system life beyond the warranty period and provides the breakeven point for warranty costs.

Model Limitations. The actual repair process at each repair level is not modeled. Instead, a probability of repair and average repair times are used to represent the repair of individual parts. These figures are provided by contractor and government analysts.

The simulation also does not include the actual procurement process for the purchase of spare engines, SRUs and LRUs, or the initial procurement of aircraft and engines. When these items are needed, they are identified and procured from outside the system.

Finally, the operations process does not simulate the actual flying of aircraft to generate engine failures. Instead the number of engine failures is a function of the number of aircraft assigned and hours flown at each base. Again, these

figures are provided by government and contractor analysts.

Model Logic. Before translating the O&S system into a computer language, the model had to be designed to move through simulated time, causing events to occur in the proper order. Since the action of each activity depended upon the state and action of other activities, they had to be coordinated or synchronized through time to simulate as close as possible the real system. A listing of the general model structure and discrete events that simulate the O&S system is displayed in Figure 3-9.

The simulation executive provides three services. It first creates all variables and arrays, then reads in all parameteric values, and finally provides the initial scheduling of the system events. There are three primary events including; deployment of aircraft, TCTO's for engine modifications, and engine inspections. All other events shown are scheduled as a result of an occurrence of one of these three major events.

Aircraft Deployment. Aircraft enter the system on a predetermined monthly schedule. The specific arrival day within each month is determined by three parameters that include aircraft production quantity, maximum aircraft quantity, and the aircraft deployment schedule.

Shown in Figure 3-10, the simulation executive preschedules all aircraft for a delivery and the deployment event brings individual aircraft into the inventory. The

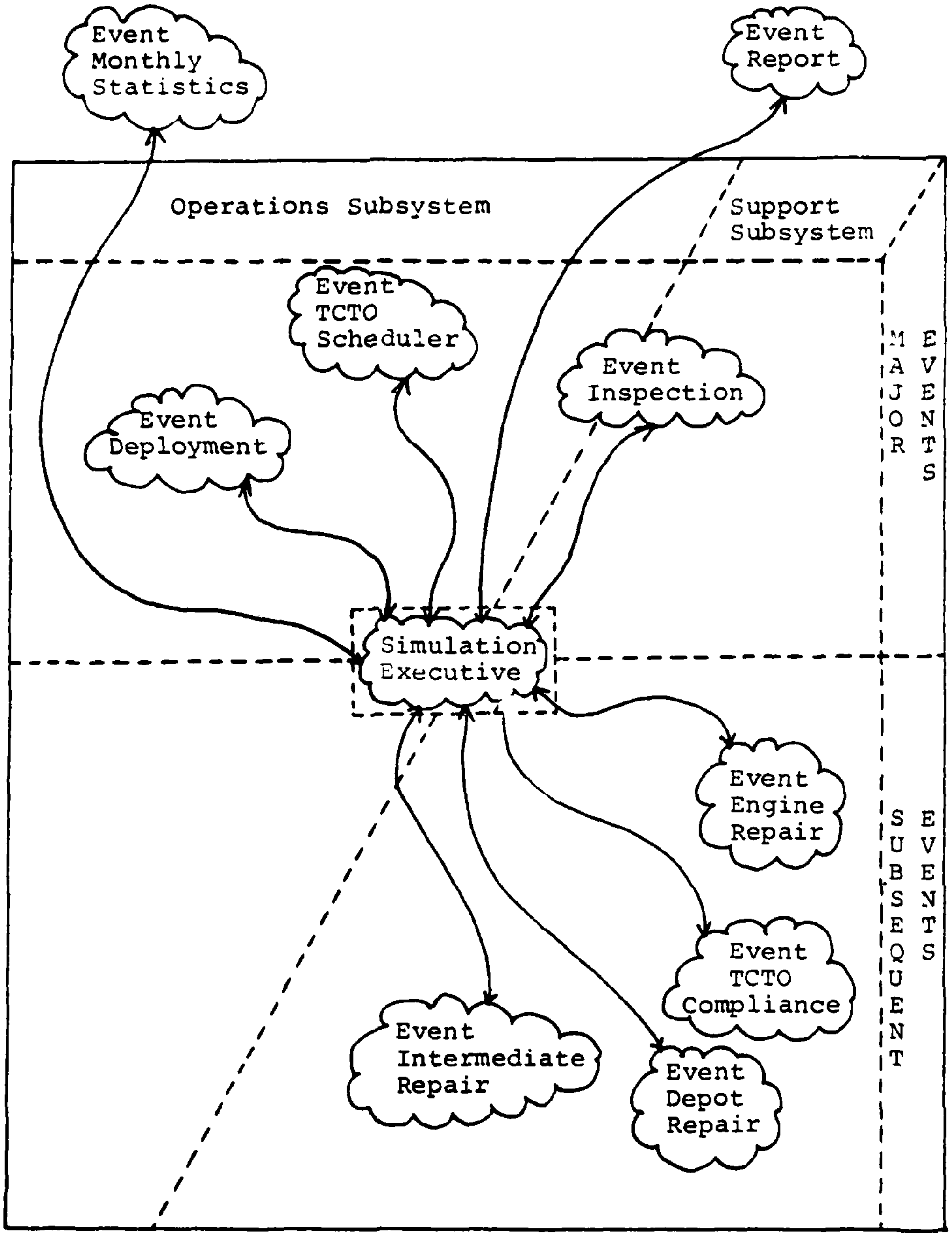


Figure 3-9 Model Logic

executive then checks the status of support equipment and, if necessary, deploys engine support equipment required at the organizational, intermediate and depot levels. The input parameter "quantity of aircraft per base" is used as a milestone for the deployment of support equipment and base activation.

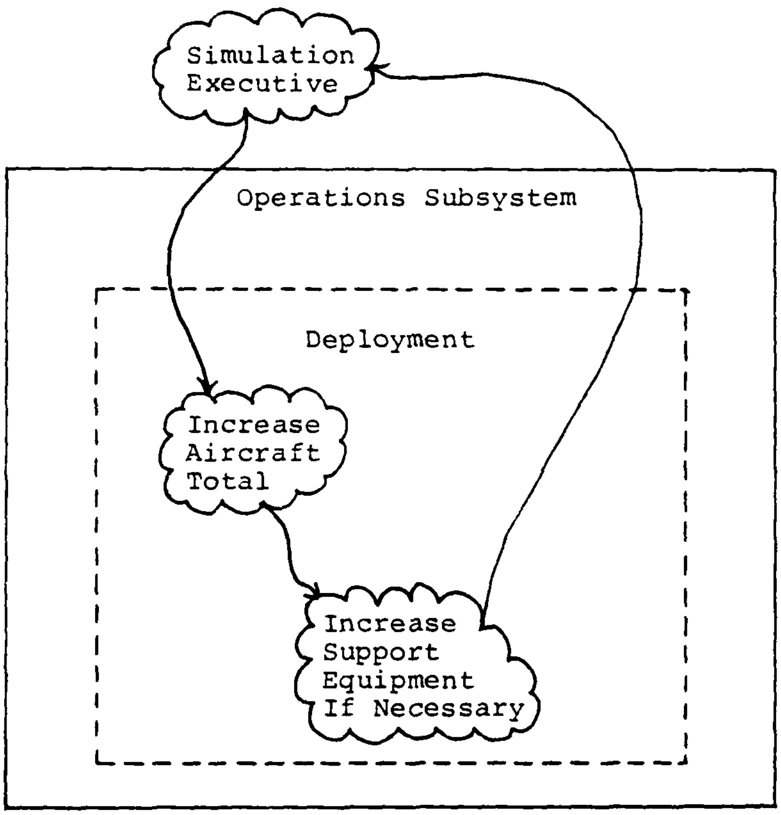


Figure 3-10 Event Deployment

When each aircraft is deployed, engine TCTO's are scheduled at some time in the future as a method of preplanned product improvement, and engine inspections are scheduled based on engine flying hours.

Engine TCTO's. The TCTO event is actually a combination of two discrete events. First, "scheduled TCTO's" are events triggered on a routine basis throughout the 20 year cycle that schedules all engines, not identified for inspections, for TCTO compliance. Second, the "TCTO compliance" event, which is the actual engine modification, is accomplished as an engine repair.

Engine Inspections. The final major event is "inspections" shown in Figure 3-11. This event controls the the largest area of the O&S system and, as indicated, directs several other subevents.

The initial inspection sequence provides accounting as it follows the total number of inspections, total organizational hours expended, and total flying hours accomplished. When an engine is identified for inspection, it is determined if the engine has failed and, if so, whether it requires removal or only LRU replacement. The engine removal probability is determined by the shop visit rate, total engines per aircraft, and the inspection frequency. If engine removal is required for repair, the initial inspection calls on the engine removal subunit. However, if only LRU replacement is required, the engine remains on the aircraft and a check of all LRUs is accomplished to determine which are to be replaced. The aircraft is then returned to service. The failed LRU or LRUs are scheduled for repair through the LRU repair event. The probability that an LRU will fail is determined by the

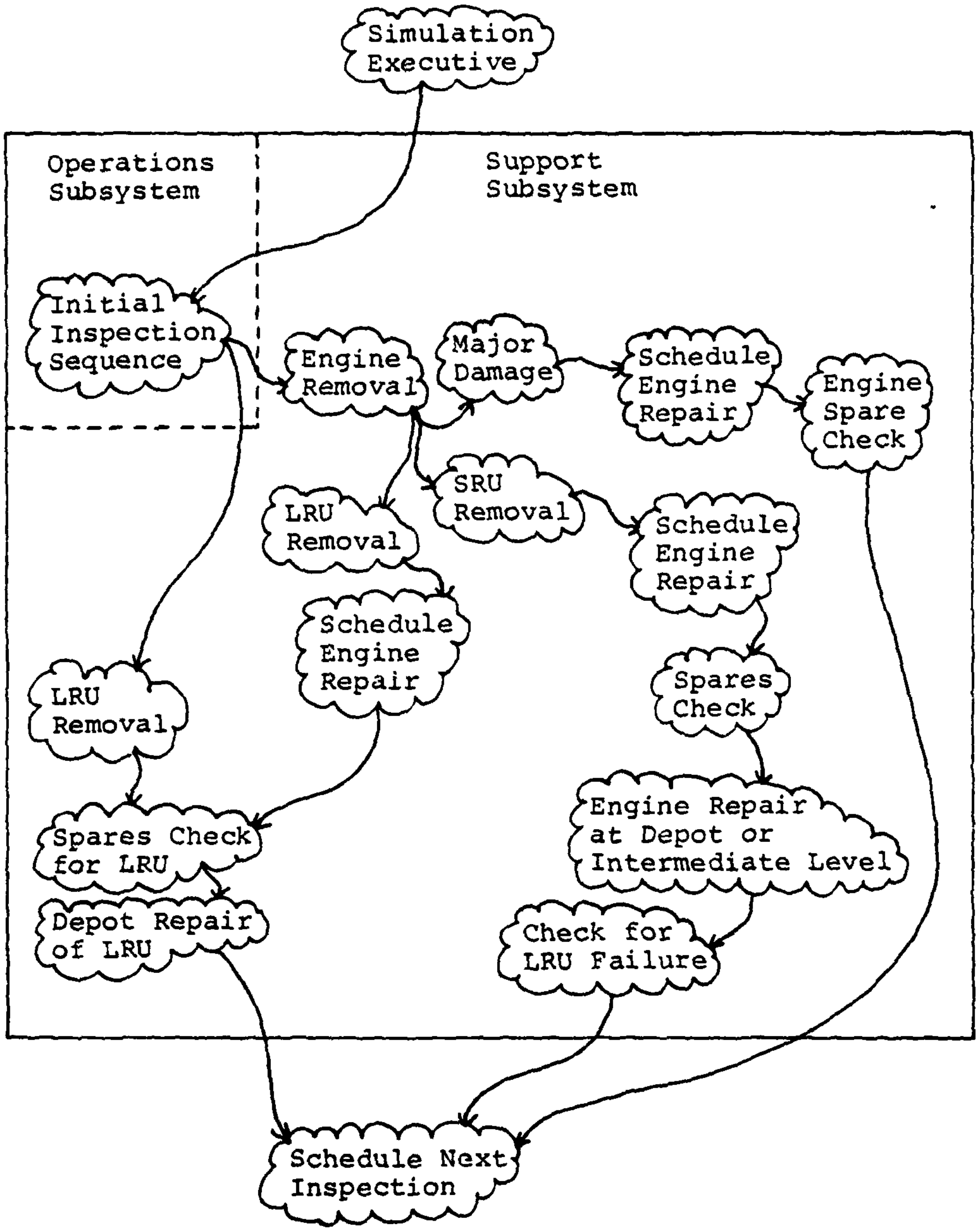


Figure 3-11 Event Inspection

LRU maintenance activities, engines per aircraft, and inspections frequency.

Engine Removal. The first subevent under inspections is engine removal. This event compiles statistics on total engine removals and organizational hours required, and determines the cause for removal. A random number generator and the failure mode distribution determine whether major engine damage, SRU failure, or LRU failure has caused the engine removal. The reason for the double check on the LRU failure is that an LRU failure may not be identified on the initial inspection and thus cause an entire engine removal. When the cause for removal is determined, the engine removal event passes control to one of the three repair subevents as appropriate, either major damage, LRU or SRU repair.

Major Engine Repair. The major damage subevent accounts for transportation time and costs to the depot, repair time and costs at the depot, and major damage removals. Engine repairs are then scheduled based on expected repair times and a spares check for engines is accomplished. "Spares check" is the subroutine which checks the level of spares for engines, LRUs and SRUs and, if necessary, procures replacements.

LRU Removal. The subevent "engine removal for LRU failure" tracks the intermediate hours required for removing the engine and schedules engine repair. It then passes action to the "check for LRU failure" subevent. This

event examines all LRUs for failure and, if a failure is encountered, the organizational, intermediate and depot repair hours are accumulated, transportation costs and times are incremented and a depot repair for each LRU is scheduled.

SRU Removal. The subevent "engine removal for SRU failure" accounts for SRU removals and the intermediate hours accrued. The engine is then scheduled for repair and the SRU repair level is determined. The SRU may be repaired at the intermediate base shop or depot level and separate subevents handle each of these possibilities. The determination as to which level, is made using random numbers and a specific probability of occurrence based on input projected maintenance action data.

Depot Repair and Intermediate Repair. The subevents for "depot" and "intermediate" repair of SRUs accomplish the same tasks. They account for the total number of repair actions and the hours required, and calculate the transportation time and cost. In addition to these actions, the SRU is scheduled for either a depot or intermediate repair event based on expected repair times. An additional check for an LRU failure is also performed since an SRU failure may mask an LRU failure.

The final step in the inspection process for each type of repair is to schedule another inspection for the aircraft and pass the process back to the simulation executive.

Intermediate and Depot Repair. The "intermediate" and "depot" repair events, Figures 3-12 and 3-13 respectively, function identically. Both determine whether LRU or SRU can be repaired. If so, they increment the particular item spares level. If the part is not reparable, then the part is condemned. The condemnation decision is based on the input condemnation factors.

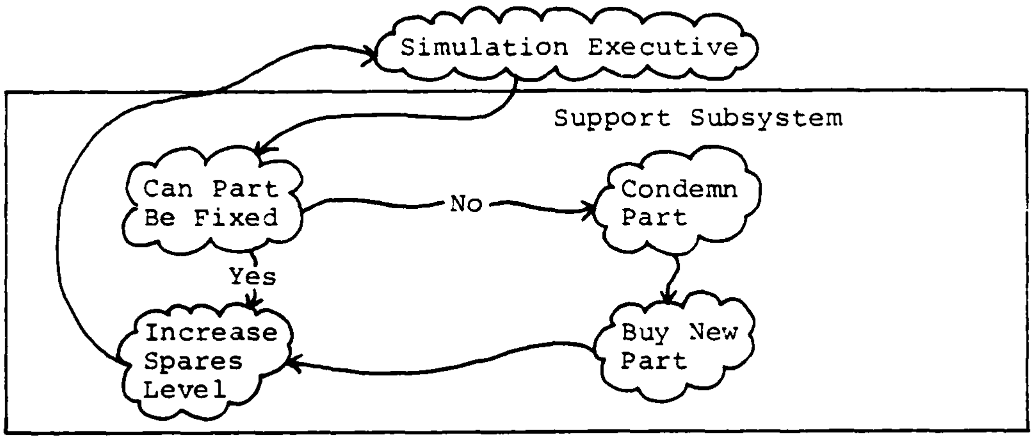


Figure 3-12 Event Intermediate Repair

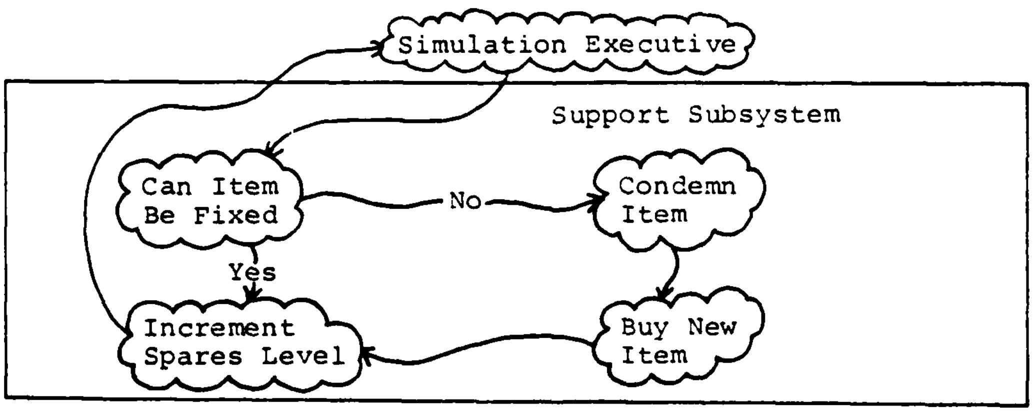


Figure 3-13 Event Depot Repair

Engine Repair. The "engine repair" event, as shown in Figure 3-14, simply increases the engine spares level by one and returns the activity to the next logical event.

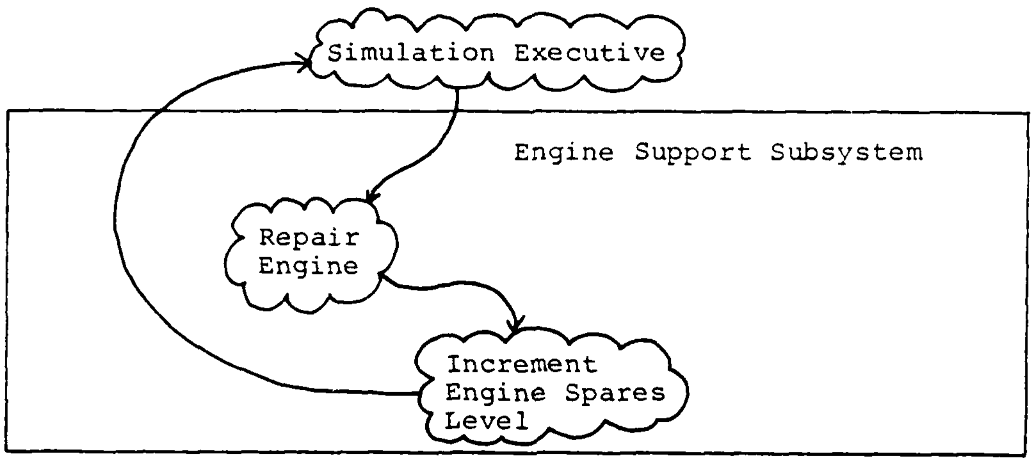


Figure 3-14 Event Engine Repair

Accounting and Reporting. The last two subevents are "accounting" and "reporting". The accounting activity shown in Figure 3-15 calculates monthly statistics necessary for determining final cost. The calculations and formulas used in this event are listed in Appendix E. The second event is the year end "reporting", Figure 3-16. This event causes the printing of the year end statistics used to analyze the cost effectiveness of the warranty.

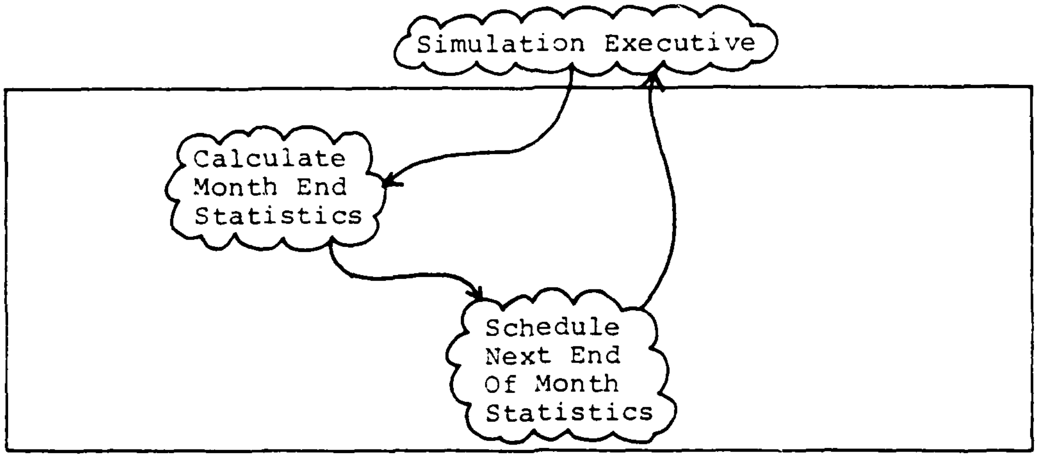


Figure 3-15 Event End of Month Statistics

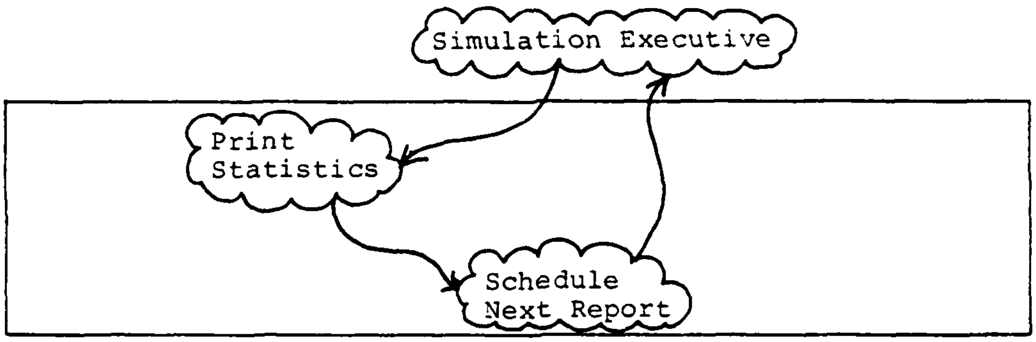


Figure 3-16 Event Report

At this point, the O&S system is sufficiently defined and structured for easy translation into a computer language. Programmers and other support personnel in YZ requested that Simscript II.5 be used as the model computer language. Additionally, they requested that the model be designed, developed and tested on the Create Computer System (15). Model coding is listed in Appendix A. Once the model was coded and debugged, the verification and validation process

was initiated.

Model Validation and Verification

The verification/validation phase of this simulation experiment was designed to ensure that any inferences drawn from the simulation would be correct and applicable to the real world system.

This process included first, a test of the logic of the model (model verification) and second, a comparison of model output to logical real world results (model validation) (18:208-210).

Model Verification. For model verification the model structure, parameters and environment were held constant during the simulation to check the internal consistency of the model. An attempt was made to insure that the event logic was correct and that the simulation process was indeed modeling all critical aspects of the engine operations system.

An important part of this test involved consultation with engine life cycle cost analysts at ASD (15; 18:228; 25). They checked the internal logic of the model and verified that from their experience and expertise that the model simulated the life cycle costs of engine operations and that the modeled warranty assumptions were valid.

Model Validation. Model validation involved the analysis of the model input/output transformation (18:210). For validation the model parameters were set and a variable seed used to provide the randomness associated with the engine

operations environment. The test of the model input/output transformations involved a comparison of model output to logical real world results.

For the engine warranty model, however, it was difficult to compare simulation output with the real world. Historical data for comparison was not available because of the limited use of warranties for engine procurement. To overcome this problem and provide the necessary model validation, model output was compared to the output of a previously validated model. In this case, the ASD Maintenance Concept Evaluation Model (MCEM) was used.

The MCEM has seen extensive use at ASD and is considered by the government as the primary LCC model for turbine engine cost analysis. Its structure and parameters are similar to those of the warranty model when the warranty parameters are suppressed thus providing the similarity necessary for comparison. An analytical comparison of the two model outputs, produced by controlled inputs, provides the basis for warranty model validation.

The testing procedure included a 20 year simulation period where each model simulated the engine operations from 1984 to 2004. Thirty simulation runs were made and four data points from each run including 1986, 1992, 1998 and 2004 were used for analysis. Figure 3-17 is an example of the data sets used in this analysis. The numbers under each year are the yearly accumulated operations costs in millions of dollars.

Simulations	MCEM 1986	MCEM 1992	MCEM 1998	MCEM 2004	WARRANTY 1986	WARRANTY 1992	WARRANTY 1998	WARRANTY 2004
1	122.51	241.81	511.06	639.00	133.05	240.92	509.01	644.29
2	131.62	256.02	518.51	645.13	121.45	253.11	519.43	638.92
3	136.33	253.34	525.25	643.10	130.41	251.00	523.20	641.02
4	128.01	262.43	519.03	638.11	135.02	262.10	518.12	639.51
*	*	*	*	*	*	*	*	*
*	*	*	*	*	*	*	*	*
*	*	*	*	*	*	*	*	*
30	125.42	252.50	520.03	643.34	123.04	251.92	520.21	642.43

Figure 3-17 MCEM and Warranty Data Sets

The four data sets from each model were tested for normality using the Lilliefors test and the population variance (5:125) for each set were tested for equality using the F test for equal population variances (two tailed). Following these tests a one-way analysis of variance (ANOVA) was performed to statistically test whether the means of the compared data sets were significantly different (5:125).

Sensitivity Analysis

Once the model had been constructed and sufficient confidence existed relative to its validity, the researchers then studied the sensitivity of the model output to changes in the identified policy parameters. While a number of methods could have been used for sensitivity analysis, the researchers

chose a three step process to identify the input factors that had the greatest effect on the system measure of performance.

The first step was to screen the five identified policy parameters to roughly visualize their individual impact on life cycle cost. To accomplish this, the researchers chose a 2^5 factorial design which identifies the parameters as factors and utilizes two levels for each to assess their effects. This method has proven useful in the early stages of other experimental work when there are many factors to be investigated.

Since an unreplicated 2^5 design existed, the researchers chose to use a technique suggested by Daniel (9) which relies on the following fact:

> If the data are normally and independently distributed, then the 2^k-1 estimates of the effects obtained from a 2^k design are normally distributed. To help identify significant effects, the estimates of the effects may be plotted on normal probability paper [14:195].

The 2^5-1 or 31 effects were computed using an algorithm proposed by Yates (26) for estimating the effects computed for the years 1986, 1992, 1998, and 2004. These results were then used in a Biomedical Plotting Program to create a normality plot.

The visualization of the effects is intended to illustrate the independent parameters and parameter combinations which show the greatest effect. For the purposes of technology demonstration, the researchers chose to use only the two parameters showing the greatest effect on the system. Step 2 involved

a further study of those two parameters. This constituted a two way analysis of variance. The two factors, A and B, were evaluated at three levels each. The data collected is in line with the structure indicated in Figure 3-18.

	B=1	B=2	B=3
A=1	$X_{A,B,K}$		
A=2			
A=3			

Where K = 1 to 30

Figure 3-18 Two Factor, Three Level Analysis Design

Thirty observations were collected for each cell and an SPSS ANOVA (5:470) program was used to assess the significance of the parameters and the interactions. Three hypotheses were posed for testing purposes.

Hypothesis I - The effects of the three levels of factor A are equal

Hypothesis II - The effects of the three levels of factor B are equal

Hypothesis III - The interaction effects of the two factors at all levels are equal

The third and final step was to use SPSS one way ANOVA with a Duncan's Multiple Comparison of Means Test (5:470) to identify homogenous subsets of means within the levels of a particular factor.

The sensitivity analysis above is provided as an example of the type of analysis which may accompany a simple cost analysis of warranty options. This provides a wealth of

information above and beyond the simple number output of the model. First it allows a comparison of significance of changes in levels of various parameters which may be subject to negotiating a contract. Additionally, it allows the analyst to target the controllable parameters which will be most useful in warranty negotiations.

Decision Support System

The purpose of the preceding model development and testing process was to provide a model and model output information that could be incorporated into a DSS which, in turn, would be used by YZL to analyze and evaluate vendor warranty proposals.

Once the basic model was verified and validated and the analysis for model sensitivity to parameter variations had identified the most important policy parameters, the model was then integrated into a decision support system that can analyze the cost effectiveness of a proposed warranty.

A negotiation process scenario was used to demonstrate how the DSS could be used in practice and is presented in Chapter IV. In this scenario both model versions are incorporated into the DSS to show their versatility. This hypothetical exercise of the DSS illustrates how this system can provide analysts with the flexibility to analyze the breakout of individual unit costs as well as to evaluate the cost effectiveness of the warranty over the life of the engine.

CHAPTER IV

RESULTS AND FINDINGS

This chapter discusses the results of implementing the experimental design of Chapter III to meet the objective and goals of this thesis. The primary objective was to provide the Propulsion System Program Office (SPO) with a decision support system to assess engine life cycle cost under warranty. To achieve this objective, the researchers determined the information required to adequately analyze the cost effectiveness of a warranty proposal. This involved a study of the engine O&S system, including the environmental elements that effect the system behavior, the development and testing of a simulation model of the O&S system, and testing the model's sensitivity to changes in various policy parameters. These three steps ultimately allowed the researchers to provide an exemplary demonstration of the decision support system's ability to establish life cycle cost estimates for engines under warranty.

System Analysis

The analysis of the engine operations and support environment was done in close cooperation with ASD LCC analysts and logisticians (15; 25). This preliminary investigation helped identify the environmental parameters that

closely describe the real world O&S system. The major engine operations and support subsystem activities and the parameters associated with those activities which resulted from this research are shown in Table 4-1. An expanded list of all system parameters and their definitions is listed in Appendix C.

TABLE 4-1

O&S System Activities and Parameters

Operations Input Parameters	Activity
Number of Aircraft/Base	Deployment
Number of Engines/Aircraft	Deployment
Maximum Number of Aircraft	Deployment
Number of Bases	Deployment

Support Input Parameters	Activity
*Shop Visit Rate	Inspection
*Total Engine Cost	Accounting
% of Aircraft Deployed Overseas	Inspection
Support Equipment Cost	Accounting
Flying Hour Program	Inspection
Inspection Frequency	Inspection
Inspection Manhours	Inspection
Manhour and Material Rates	Accounting
Engine Overhaul Hours	Inspection
Transportation Times	Inspection
Total Depot Repair	Inspection
Total Base Repair	Inspection
Transportation Cost	Accounting
Inflation Rate	Accounting
Discount Rate	Accounting
First Year of Simulation	Accounting
Interval Between Reports	Accounting
Interval Between TCTO's	Schedule TCTO
Failure Mode Distribution	Inspection
*Maintenance Action Levels	Inspection
*Maintenance Manhours	Inspection
Parts Cost	Accounting
*Condemnation Factor	Inspection

Among the parameters listed in Table 4-1 are the five policy

parameters (*) referred to earlier. They include total engine cost, reliability (maintenance action levels), maintainability (maintenance manhours), shop visit rate and condemnation factor. The analysis of these five parameters, including their individual and interactive effects on model output is addressed in the model sensitivity analysis section of this chapter.

This system study provided the background data necessary to construct the warranty simulation model.

Model Development

In order to fully analyze engine warranty options, Propulsion analysts felt that two versions of the simulation model would be required. As indicated in Chapter III, these two versions differ only in output, not in their internal logic.

Model Output - First Version. The first version of the model provides a monthly breakout of the factors that make-up the final O&S cost. This version is used for specific unit cost analysis for the warranty period. An example of the model output is shown in Figure 4-1. The coded model is listed in its entirety in Appendix B.

The final output of this version first provides total engine and fleet flying hours and the number of inspections performed over the simulation period. The output also includes on-wing maintenance activity which includes the number of LRUs removed and the LRU repair cost at each repair level.

Engine removal output information is also included.

```
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

              FYXX  STATUS REPORT-CY 1987.75

     53200.00 ENGINE FLYING HOURS
     13300.00 FLEET FLYING HOURS
                   256 INSPECTIONS PERFORMED

ON-WING MAINTENANCE ACTIVITY
  TO DATE   234  LRUS HAVE BEEN REMOVED, TOTAL MHRS & LABOR ARE
  O-LEVEL=$    3741.60, I-LEVEL=$   27993.00 ,D-LEVEL=$  310045.00
  DISTRIBUTED AMONG THE 16 IDENTIFIED LRUS AS FOLLOW:
  28    6    1   123   64    2    3   22   14    7    4    2   30    4    8   16

ENGINE REMOVAL INFORMATION
 135 ENGINES REMOVED (TOTAL EXCLUDING TCTOS)
     15 ENGINES REMOVED - MAJOR ENGINE DAMAGE
     15 ENGINES REMOVED - MINOR REPAIR - LRU
    105 ENGINES REMOVED - SRU CAUSED
  27 ENGINES REMOVED - TCTO

  TO DATE   424 SRU MAINTENANCE ACTIONS HAVE TAKEN PLACE, DIVIDED AS
   (I-LEVEL=  206,$ 1156337.54, D-LEVEL=  218,$ 1853299.75) AND
    DISTRIBUTED AMONG THE 20 IDENTIFIED SRUS AS FOLLOW:
  17   15    9    9    8   10   23   25    3   50   14   50   34   35   22   32   25   22   11    5

SPARE ENGINE REQUIREMENTS (FAILURES AND TCTOS)     20  $130000000.00

SPARE SRU REQMTS (PIPELINE  $ 1203740.00   BROKEN DOWN AS FOLLOWS:
  4   2   3   2   2   4   7   6   2   8   4  10   9   6   7   8   6   5   2   3
SPARE SRU REQMTS (CONDEMS)  $  1636794.00   BROKEN DOWN AS FOLLOWS:
  0   1   1   0   0   0   0   0   0  13   0   0   1   2   1   3   0   0   1   0
SPARE LRU REQMTS (PIPELINE) $  2455767.00   BROKEN DOWN AS FOLLOWS:
 12   4   1   9  22   2   2  12   5   6   2   1  27   4   4   5
SPARE LRU REQMTS (CONDEMS)  $   230393.00   BROKEN DOWN AS FOLLOWS:
  1   0   0   0  41   0   0   1   0   0   2   1   5   0   0   1
                    ORG-LEVEL          INTER-LEVEL        DEPOT LEVEL
MAINTENANCE
 MANHOURS               3603              34528              44157
 DOLLARS        $   206481.00      $  1208480.00      $  2505844.00
SUPPORT EQUIPMENT
 UNITS                     2                  2                  1
 DOLLARS        $  2100000.00      $  9750000.00      $ 52500000.00

TRANSPORTATION REQUIREMENTS=$    35280.00

              TOTAL COST=$ 213816778.00

              INFLATED COST =$ 231659436.00

              DISCOUNTED COST =$ 213816770.00

              COST/EFH = $       4019.11

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
```

Figure 4-1 Short Version Output

This lists and catagorizes failure-caused removals as well as removals for TCTO action. A total for all engine removals is also provided.

Next, the three level maintenance manhours and costs and support equipment costs are given along with the final cost for transportation to the depot repair facility. The last output is final O&S cost which is inflated and then discounted to give a realistic cost comparison.

This output provides the Propulsion SPO with the information they need to track the individual repair costs in an easily read format for assessing cost effectiveness of a warranty which has specific coverages. For example, if the contractor has proposed a warranty for the repair and replacement of all engine LRUs for a specified period of time this model would perform as follows. It would simulate the O&S system for this period and provide YZ analysts with a monthly breakout of the LRU support costs. This allows a comparison of the expected support costs to the cost of the warranty and thus facilitates a cost effectiveness decision.

Model Output - Second Version. The second version is designed to suppress the breakout of specific unit cost and provide only year end final costs. The abbreviated output format, Figure 4-2, delivers only the yearly accumulated cost after inflating and discounting.

```
FXXX  STATUS REPORT-CY 1986.00
 DISCOUNTED COST =$  90763643.00
FXXX  STATUS REPORT-CY 1987.00
 DISCOUNTED COST =$ 125706476.00
FXXX  STATUS REPORT-CY 1988.00
 DISCOUNTED COST =$ 255478980.00
FXXX  STATUS REPORT-CY 1989.00
 DISCOUNTED COST =$ 343905808.00
FXXX  STATUS REPORT-CY 1990.00
 DISCOUNTED COST =$ 384967704.00
FXXX  STATUS REPORT-CY 1991.00
 DISCOUNTED COST =$ 402664576.00
FXXX  STATUS REPORT-CY 1992.00
 DISCOUNTED COST =$ 420525760.00
FXXX  STATUS REPORT-CY 1993.00
 DISCOUNTED COST =$ 439961712.00
FXXX  STATUS REPORT-CY 1986.00
 DISCOUNTED COST =$  90074101.00
FXXX  STATUS REPORT-CY 1987.00
 DISCOUNTED COST =$ 125658383.00
FXXX  STATUS REPORT-CY 1988.00
 DISCOUNTED COST =$ 236210102.00
FXXX  STATUS REPORT-CY 1989.00
 DISCOUNTED COST =$ 329671828.00
FXXX  STATUS REPORT-CY 1990.00
 DISCOUNTED COST =$ 367444912.00
FXXX  STATUS REPORT-CY 1991.00
 DISCOUNTED COST =$ 387159476.00
FXXX  STATUS REPORT-CY 1992.00
 DISCOUNTED COST =$ 403725012.00
FXXX  STATUS REPORT-CY 1993.00
 DISCOUNTED COST =$ 433623260.00
```

Figure 4-2 Long Version Output

This version looks beyond the warranty period and determines if the engine part reliability and maintainability improvements made by the contractor during the warranty period are substantial enough to warrant the front-end warranty cost. If they are, then at some point in time in the future prior to the end of the engine life cycle a breakeven point will be reached, indicating that maintainability costs to the government

are reduced because of the part reliability improvements.

This version also has the capability of multiple simulations. Up to 10 simulations can be performed in a single run. The program listing is found in Appendix A.

Once the model had been constructed and was providing engine warranty information, it was verified, validated, and tested for sensitivity to level changes in the five policy parameters.

Model Verification

The process of verification was defined in Chapter III as a test of model logic. A Turing test was chosen as the most feasible method of model logic assessment.

The model and four sets of model output were given to Propulsion logistics personnel for their review. They found that the model logic was in agreement with their understanding of the engine O&S system and verified the assumptions made for the warranty aspects of the model to be correct. Once verification was completed, the next step was to validate the model and its output.

Model Validation

Model validation is a comparison of the simulation model to output of the real world system. However, as indicated in the preceding chapter, no real world data is currently available to assess the warranty model reliability. Therefore, the Maintenance Concept Evaluation Model (MCEM) was used as a basis for model evaluation. Thirty independent simulations of

each model were made. The total accumulated costs were collected at four points throughout the 20 year simulation. Each simulation began in 1984 and data were collected at four points for analysis. These points included 1986, 1992, 1998, and 2004. The data for the MCEM model is shown in Table 4-2 and for the warranty model in Table 4-3.

The intent of this testing was to determine if any significant difference existed between the results of the two simulations. The four yearly data points were used to insure that there was no significant difference during the entire life cycle simulated. Two basic assumptions had to be substantiated before the data from these two models could be tested. First, since it was necessary to assume both samples came from normally distributed populations, a Lilliefors Test was made to detect any significant deviation from normality. The null hypothesis was:

H_o: The distribution is normal for each sample,

with the alternate being:

H_a: The distribution is not normal for each sample.

The test statistic for comparison was a Lilliefors value of .161 assuming an alpha value of .05. The decision rule is as follows:

> If the Maximum Absolute Difference that is calculated is greater than the Lilliefors Table Value then the Null hypothesis is rejected and the distribution of the sample is assumed not to be normal.

The results of this testing are shown in Table 4-4 and indicate

TABLE 4-2 MCEM Output Data

Run	1986	1992	1998	2004
1	111.70	450.87	559.59	667.05
2	117.93	431.96	549.12	656.06
3	116.97	450.00	561.28	690.60
4	111.32	421.27	536.14	651.20
5	104.97	424.13	537.19	664.29
6	125.92	443.63	565.03	676.34
7	104.71	455.40	560.91	669.35
8	96.80	420.32	542.71	663.36
9	111.63	441.35	561.82	667.39
10	97.50	454.77	565.17	671.17
11	103.60	442.77	551.18	661.20
12	112.86	444.64	550.58	655.96
13	103.64	427.96	538.25	658.95
14	112.52	422.28	534.66	645.81
15	103.26	430.20	555.65	668.99
16	116.73	413.00	555.14	683.62
17	118.90	429.09	543.57	650.83
18	104.93	450.17	559.80	663.99
19	118.48	440.68	555.30	668.23
20	105.57	443.22	557.30	660.84
21	112.05	424.46	535.42	644.62
22	109.72	424.74	534.61	655.53
23	98.04	436.90	558.60	668.43
24	104.29	422.90	550.69	650.69
25	96.91	452.90	560.64	669.82
26	112.10	435.98	561.08	672.40
27	110.85	457.53	568.28	674.15
28	113.33	436.61	556.93	662.57
29	116.62	424.28	545.37	651.22
30	118.23	443.36	549.12	662.28
Means	109.74	436.58	551.44	663.56

TABLE 4-3 Warranty Model Output Data

Run	1986	1992	1998	2004
1	123.84	463.36	577.70	684.81
2	109.20	428.70	541.53	663.87
3	104.05	422.36	578.13	684.61
4	124.30	424.17	537.08	675.13
5	105.13	420.16	541.52	654.92
6	111.56	431.02	560.62	672.98
7	116.99	453.60	562.38	671.51
8	116.82	436.82	552.04	664.06
9	97.59	436.68	549.09	667.41
10	117.37	427.89	545.57	667.53
11	116.51	436.11	540.65	647.15
12	111.95	453.57	560.20	666.30
13	111.44	432.50	540.55	671.79
14	112.16	443.94	551.49	660.48
15	126.13	462.72	571.63	673.11
16	110.58	421.70	541.50	655.86
17	116.80	438.75	551.56	678.56
18	118.02	450.44	559.12	672.45
19	110.55	440.33	551.48	660.90
20	111.99	415.64	546.67	654.18
21	117.81	427.24	570.32	679.04
22	103.20	443.39	551.53	672.02
23	103.84	419.03	538.81	642.73
24	117.05	446.19	566.13	670.44
25	119.30	446.51	552.50	656.43
26	105.05	410.31	521.26	629.36
27	108.36	418.66	556.03	667.37
28	105.01	450.22	558.92	667.73
29	119.67	433.70	552.24	669.72
30	104.08	441.14	544.17	683.59
Means	112.55	435.90	552.41	666.20

that all eight distributions were in fact normally distributed.

TABLE 4-4

Normality Test (MCEM & Warranty Output)

Data Set		Mean (Millions)	Std Dev (Millions)	MAX ABS Diff
MCEM	1986	109.74	7.47	.1260
MCEM	1992	436.58	12.42	.1297
MCEM	1998	552.04	10.23	.1525
MCEM	2004	663.57	10.57	.0785
WARR	1986	112.55	7.09	.1453
WARR	1992	435.90	13.85	.0692
WARR	1998	552.41	12.72	.1306
WARR	2004	666.20	12.41	.1375

The second assumption that had to be made was that each population had the same variance. This involved a comparison of the variances of the two models at each of the four years. The Null hypotheses was as follows:

$$H_o: \sigma^2_{\text{warranty for 1986, 1992, 1998, 2004}} = \sigma^2_{\text{MCEM for 1986, 1992, 1998, 2004}}$$

with the alternate being:

$$H_a: \sigma^2_{\text{warranty for 1986, 1992, 1998, 2004}} \neq \sigma^2_{\text{MCEM for 1986, 1992, 1998, 2004}}$$

The test statistic for comparison was the F value:

$$F_{\alpha/2,(N_1-1),(N_2-1)} = 1.85$$

where: $\alpha/2 = .05$
$N_1 = 30$
$N_2 - 30$

The decision rule for the F-Test was:

If the calculated F is greater than 1.85 then the variances are not equal

$$\text{where:} \quad F = \frac{\text{larger } \sigma^2}{\text{smaller } \sigma^2}$$

The results of these calculations are shown in Table 4-5. These indicate that in no case can the hypothesis that the variances are equal be rejected.

TABLE 4-5

Comparison of Variances
(MCEM & Warranty Output)

Year	Model	Variance	Test Statistic Computation	Comparison
1986	WARR.3	48.597	$\frac{53.868}{48.597} = 1.108$	$1.108 \not> 1.85$
	MCEM.3	53.868		
1992	WARR.3	185.330	$\frac{185.330}{149.154} = 1.243$	$1.243 \not> 1.85$
	MCEM.3	149.154		
1998	WARR.3	156.493	$\frac{156.493}{113.256} = 1.382$	$1.382 \not> 1.85$
	MCEM.3	113.256		
2004	WARR.3	148.810	$\frac{148.810}{108.076} = 1.377$	$1.377 \not> 1.85$
	MCEM.3	108.076		

With the two basic assumptions supported, it was possible to analyze the means of each of the simulations. This analysis was accomplished using a Oneway ANOVA to compare the means of the two simulation populations for each year group. The hypothesis to be tested is as follows starting with the Null:

H_o: The mean for each year group of the MCEM model output is equal to its respective output of the warranty model

The alternate hypothesis is:

H_a: The means of the respective models are not equal

The test statistic for this analysis is a comparison of the F probability from the SPSS Oneway analysis to the chosen alpha level of .10. The decision rule is as follows:

> If the F probability, or P value as it is referred to, associated with a computed value of the F Test statistic is less than the alpha value then the means are not equal.

The results of this testing are reported in Table 4-6 and indicate that the P values are greater than the alpha value in all cases. This precluded rejecting the hypothesis that there was no significant difference between the average costs of each simulation at the four data collection points.

The SPSS programs used for analysis are provided in their entirety in Appendix H.

TABLE 4-6

Oneway ANOVA
(MCEM & Warranty Output)

Year	P-Value*	Warranty Mean (Millions)	Maintenance Mean (Millions)
1986	.1407	112.55	109.74
1992	.8411	435.90	436.58
1998	.9136	551.75	552.06
2004	.3793	666.20	663.56

*P-Value - The probability of obtaining a value of the F Test statistic at least as large as the reported F Value

Sensitivity Analysis

Testing of the model demonstrated its validity in the real world situation. Next, the researchers tested the model's sensitivity to changes in policy parameter levels to determine which parameters had the greatest effect on system behavior. This process involved first a screening of the five policy parameters to determine the two most dominant parameters and second, an extensive analysis of these two parameters. It was initially decided that two parameters would be analyzed in order to limit the total number of required simulations.

The first step in the screening process involved collecting the data of the effects of parameter change on model output for each of the five policy parameters and all their possible combinations. The treatment levels were

arranged in standard order shown in Table 4-7.

TABLE 4-7

Policy Parameter Treatment Levels
Standard Order

A
B
AB
C
AC
BC
ABC
D
*
*
*
ABCDE

With all other parameter values held at their normal level, the values of the parameter or parameter combinations shown in Table 4-7 were changed to reflect an improvement. Table 4-8 identifies each policy parameter with its corresponding factor and shows the parameter value levels that were used in the sensitivity analysis.

TABLE 4-8

Policy Parameter Changes

Factor	Title	Standard	Change
A	Engine Cost	\$6.5M	\$5.85
B	Reliability	0%	+10%
C	Maintainability	0%	+10%
D	Shop Visit Rate	2.5	2.25
E	Condemnation Factor	0%	-10%

Thirty simulation runs of each parameter combination were made. The average response for four of the thirty years is shown in Table 4-9.

TABLE 4-9 Yates Algorithm Inputs

Response	1986	1992	1998	2004
1	127.39	449.13	566.60	680.52
A	123.11	426.30	542.54	656.24
B	126.97	447.04	552.66	655.07
AB	122.68	423.38	526.67	630.56
C	127.32	444.20	556.18	664.64
AC	123.03	421.41	532.52	640.46
BC	126.90	442.67	543.24	640.64
ABC	122.61	418.81	519.00	616.14
D	124.30	435.96	554.83	666.90
AD	120.34	414.32	532.15	643.39
BD	124.08	427.65	529.55	634.65
ABD	120.05	405.81	507.25	611.77
CD	124.23	431.09	544.49	651.08
ACD	120.27	409.44	521.80	628.07
BCD	124.01	423.24	520.19	620.30
ABCD	119.98	401.40	497.89	597.42
E	127.34	445.78	559.20	667.79
AE	124.72	427.59	539.06	644.89
BE	126.96	443.97	545.90	644.45
ABE	122.67	420.31	521.66	620.04
CE	129.06	445.68	552.09	652.67
ACE	124.65	422.61	528.03	628.88
BCE	125.66	437.37	532.38	630.12
ABCE	122.60	415.94	512.25	605.61
DE	124.30	432.48	547.30	655.20
ADE	120.33	410.93	524.51	632.18
BDE	124.03	424.83	523.29	624.42
ABDE	120.13	402.99	500.99	601.54
CDE	125.04	429.03	539.01	641.92
ACDE	121.01	407.32	516.26	618.52
BCDE	121.16	421.68	518.05	607.85
ABCDE	119.39	399.51	495.30	587.25

The data in each year group was analyzed using the Yates Algorithm (26) which calculated an estimated effect for each parameter set shown in Table 4-10. To help isolate the two most important policy parameters the data produced by the Yates Algorithm was plotted using the BMDP package on the ASD CYBER system. The program that was used can be found in Appendix I and the normality plots for each year group are shown in Figures 4-3, 4-4, 4-5, and 4-6.

It is apparent that factors A and D are dominant over the majority of the life cycle and these two factors should be selected for further study. However, the results in general provided increased confidence in the model as the effects of each factor responded in a manner that was intuitively appealing. It was expected that engine cost (A) and shop visit rate (D) would be strong drivers over the entire system life, and that the effects of reliability (B), maintainability (C), and condemnation (E) would begin to increase as the system matured and gained flying hours.

The screening process identified the two most dominant parameters. These two parameters could then be further tested to determine if their effects were truly significant and if there was any significant interaction between them. A Two Way ANOVA was used to test the following Null hypothesis:

H_o: Are the effects of factor A significant

H_o: Are the effects of factor D significant

TABLE 4-10 Yates Algorithm Results

Response	1986	1992	1998	2004
1	-	-	-	-
A	-3.82	-22.11	-22.92	-22.12
B	-1.04	-6.04	-19.42	-26.63
AB	0.12	-0.43	-0.11	-1.24
C	-0.16	-4.19	-9.12	-16.17
AC	0.09	-0.21	0.10	1.31
BC	-0.50	-0.23	0.41	1.51
ABC	0.33	0.42	0.58	-1.03
D	-3.19	-15.91	-16.10	-14.75
AD	0.12	0.33	0.35	-0.54
BD	0.16	-1.99	-4.06	-4.94
ABD	0.16	0.29	0.27	1.64
CD	-0.15	0.16	0.76	1.40
ACD	0.17	0.15	-0.15	-1.08
BCD	-0.13	0.40	0.50	-1.64
ABCD	-0.05	-0.44	-0.64	1.36
E	-0.11	-2.11	-5.79	-9.69
AE	0.32	0.41	0.52	-1.03
BE	-0.70	-0.81	-0.04	-0.96
ABE	0.14	-0.14	0.15	1.31
CE	-0.08	0.47	0.55	1.45
ACE	0.10	-0.18	-0.12	-1.19
BCE	-0.50	-0.45	-0.31	-1.72
ABCE	0.33	0.45	0.36	1.47
DE	-0.35	-0.40	0.36	-0.96
ADE	-0.03	-0.44	-0.60	1.26
BDE	0.08	1.05	1.15	0.84
ABDE	0.17	0.10	-0.19	-0.98
CDE	-0.16	0.14	0.94	-1.13
ACDE	0.16	0.12	0.07	1.43
BCDE	-0.13	0.39	0.76	0.86
ABCDE	-0.05	-0.47	-0.42	-1.14

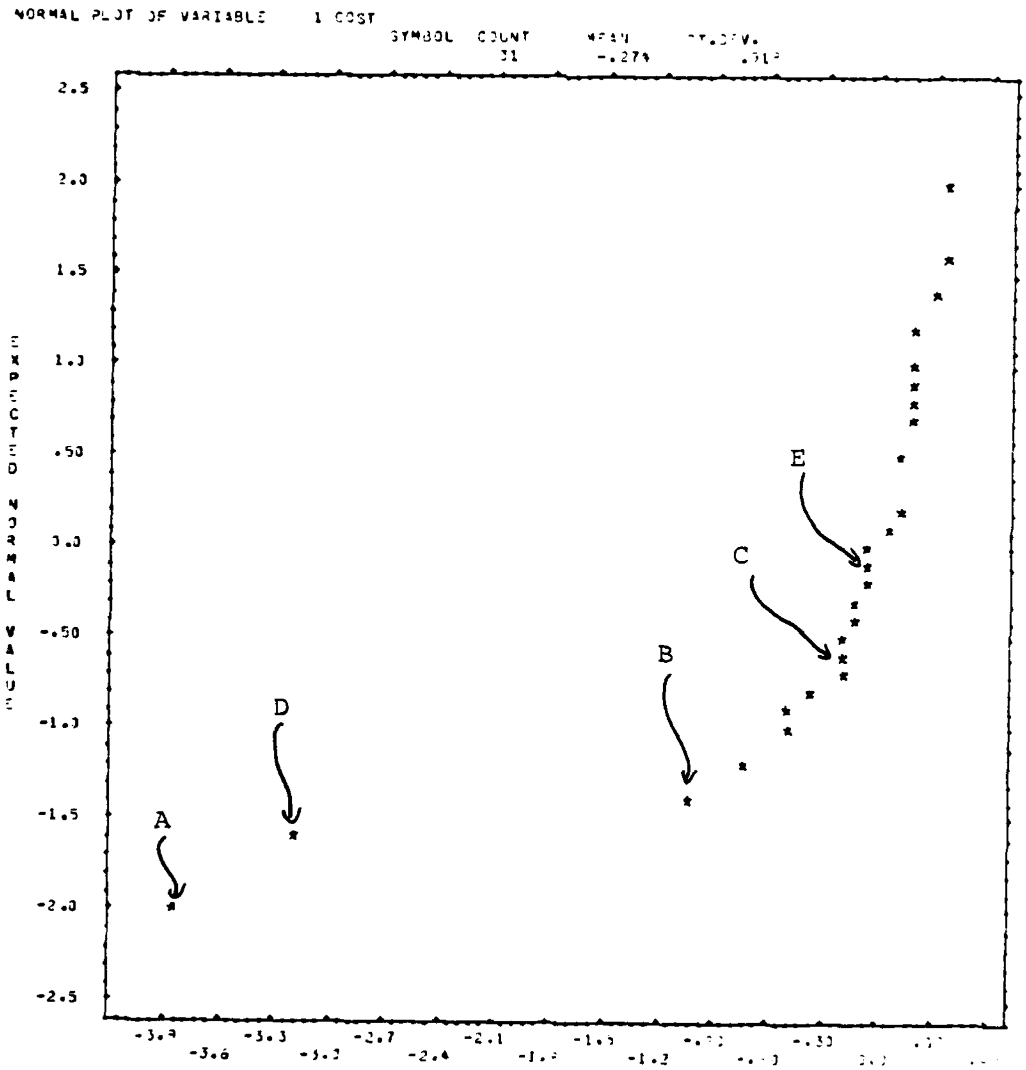


Figure 4-3 1986 Normality Plot

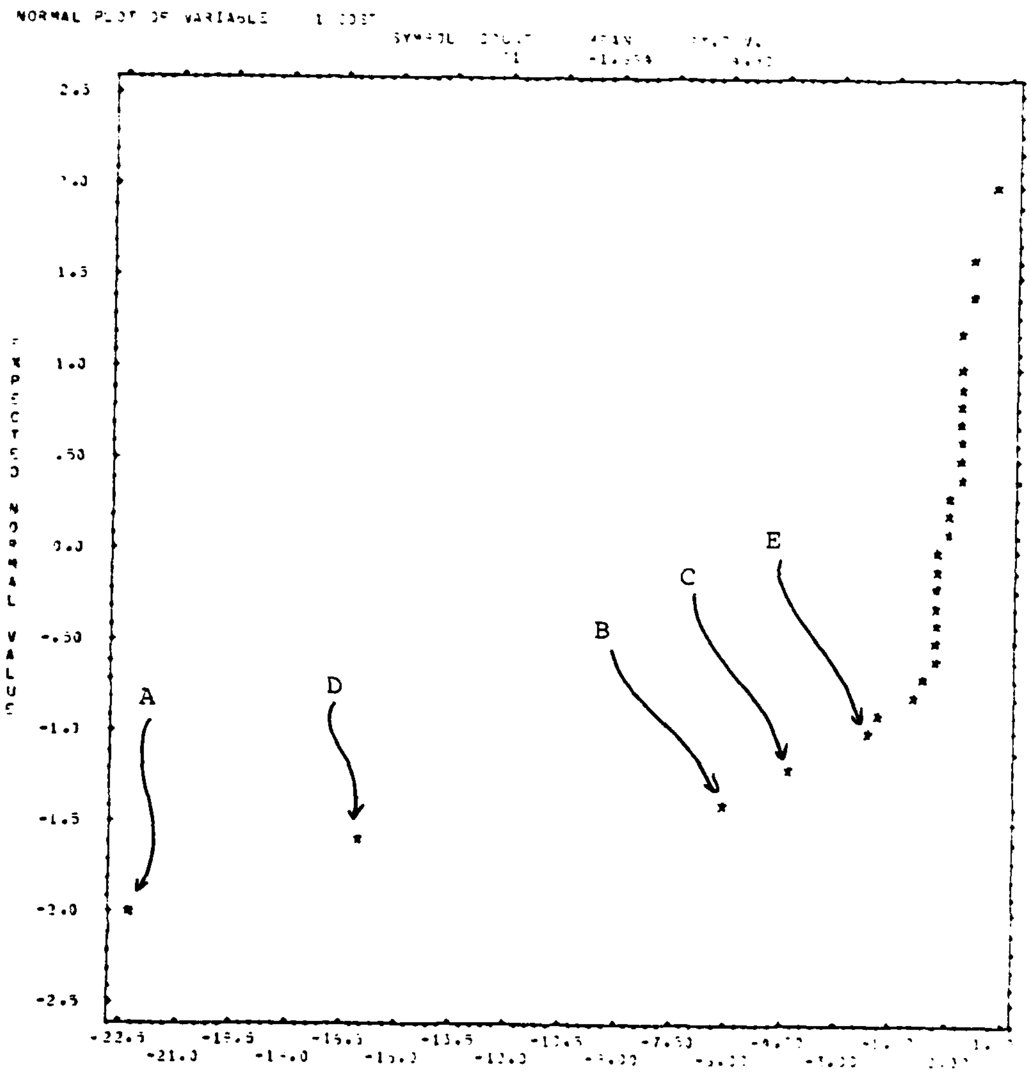


Figure 4-4 1992 Normality Plot

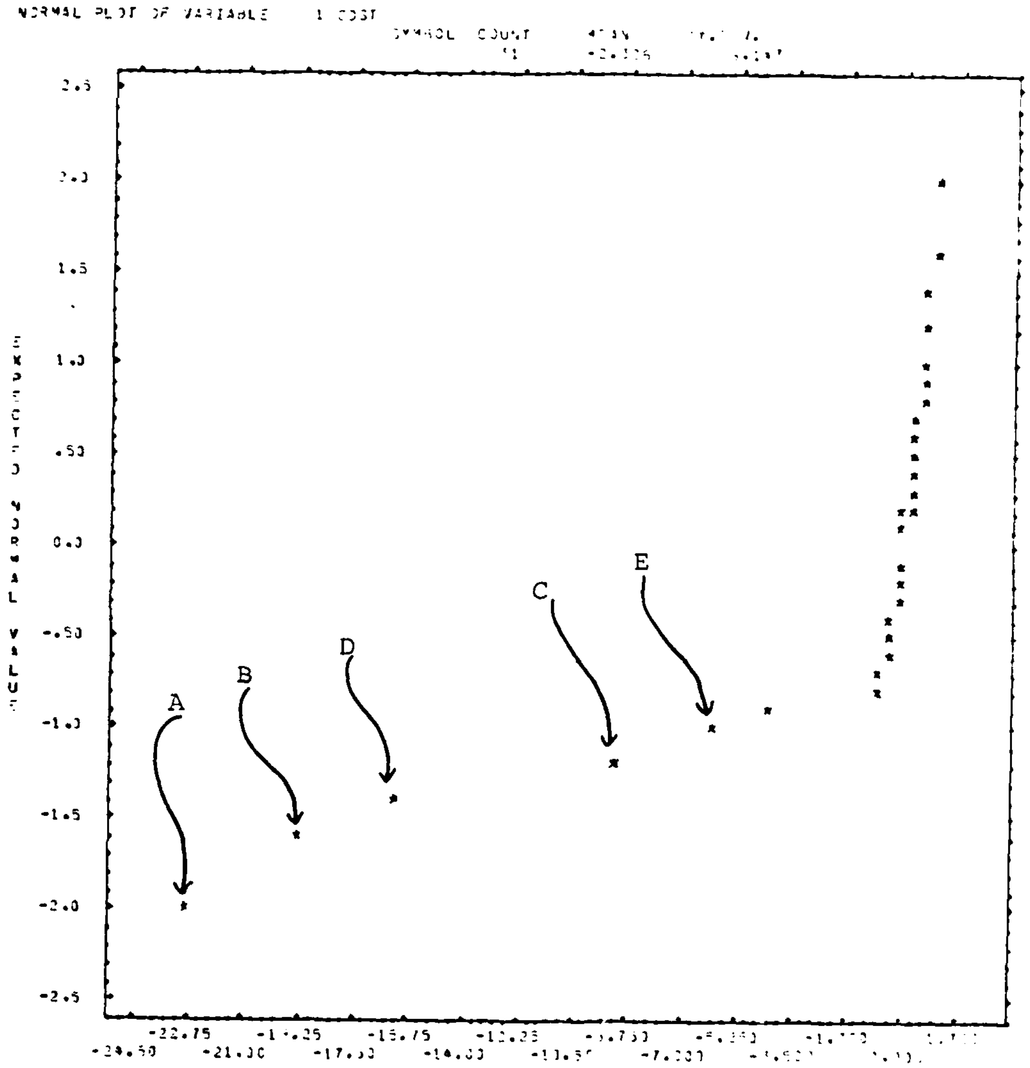


Figure 4-5 1998 Normality Plot

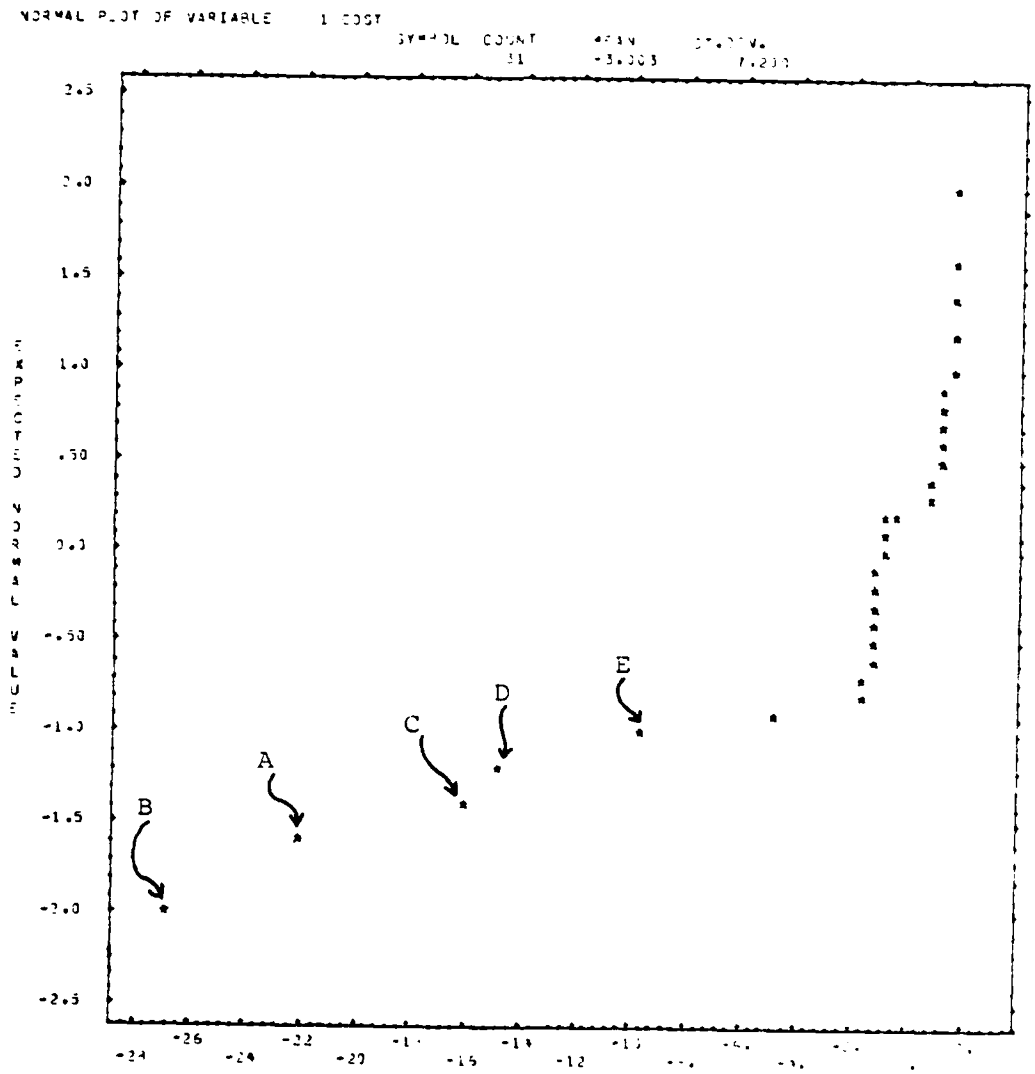
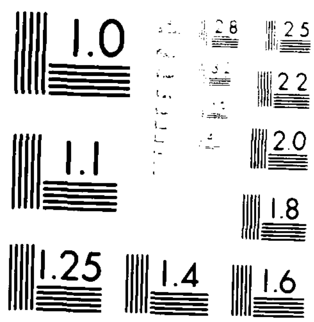


Figure 4-6 2004 Normality Plot

AD-A123 034 COST ANALYSIS OF TURBINE ENGINE WARRANTIES(U) AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOOL OF SYSTEMS AND LOGISTICS G T HELLESTO ET AL. SEP 82 2/3

UNCLASSIFIED AFIT-LSSR-85-82 F/G 21/5 NL


1.0
2.8
2.5
2.2
1.1
2.0
1.8
1.25
1.4
1.6

H_o: Are the interaction effects of A and B significant

In order to use this analytic method, 30 observations for each possible combination of the two factors at three levels were needed. The design for generating this data is shown in Figure 4-7 and the actual observations are listed in Table 4-11.

Shop Visit Rate
D

Engine Cost A

i \ j	1	2	3
1	$X_{1,1,K}$	$X_{1,2,K}$	$X_{1,3,K}$
2	$X_{2,1,K}$	$X_{2,2,K}$	$X_{2,3,K}$
3	$X_{3,1,K}$	$X_{3,2,K}$	$X_{3,3,K}$

K=1-30

Figure 4-7 Data Generating Design for Two Way ANOVA

Using this data a Two Way ANOVA of the three levels of engine cost was run. The Null Hypothesis was:

H_o: Are the effects of factor A significant

and the decision rule was:

> If $F > F_{\alpha/2\,(K-1)\,(N-K)}$ (where K is the total number of levels and N is the number of observations) then there is a significant difference in at least two of the three levels.

If $\alpha/2 = .05$, $K-1 = 2$, and $N-K = 261$ then the F Table value

$F_{.05,\ 2,\ 261} = 3.00$

The Two Way ANOVA calculated an F Value of 320.015,

TABLE 4-11 Policy Parameter Output

Shop Visit Rate Level 1			Shop Visit Rate Level 2			Shop Visit Rate Level 3		
Engine Cost Level			Engine Cost Level			Engine Cost Level		
1	2	3	1	2	3	1	2	3
407.29	428.09	448.89	423.79	442.83	463.45	429.56	459.29	477.70
421.49	444.24	483.52	412.43	445.89	476.74	437.53	459.48	483.43
425.93	448.68	500.05	420.79	434.53	464.74	441.92	463.20	490.01
403.21	424.01	449.81	425.32	448.07	467.99	468.86	454.30	474.96
445.46	470.16	467.23	433.30	456.70	491.69	435.89	454.29	486.03
416.59	438.04	459.63	428.31	451.03	486.09	435.44	459.38	486.15
415.78	437.21	456.32	440.57	464.62	491.26	439.14	465.96	517.86
404.08	424.88	449.51	413.97	436.07	471.32	430.90	452.21	493.86
407.13	427.93	456.19	438.93	462.98	479.64	430.89	461.98	489.11
396.24	416.39	465.73	425.58	448.31	472.55	435.32	462.10	481.55
402.26	422.41	458.75	464.53	562.99	463.45	441.91	491.21	491.65
414.77	436.32	459.25	436.40	436.44	476.98	429.46	469.82	493.32
432.67	456.07	457.77	425.01	462.38	489.66	437.93	465.06	476.77
423.39	446.14	452.94	401.56	452.24	489.35	438.05	458.15	484.37
414.46	436.59	465.69	438.94	456.65	485.17	464.56	467.60	484.36
411.18	441.48	462.87	414.34	460.87	461.87	445.77	468.63	496.63
424.64	427.80	464.59	438.33	454.57	487.91	441.01	454.03	521.93
411.71	431.42	449.78	429.53	462.25	485.33	434.75	460.97	495.81
428.66	436.56	451.30	433.25	448.18	472.49	443.55	460.96	471.19
412.95	432.63	459.62	436.82	463.68	471.87	443.92	471.94	498.05
410.93	416.74	428.91	431.17	464.47	451.68	431.28	494.63	482.13
453.72	433.16	465.37	438.20	439.27	485.77	437.57	471.11	482.98
414.30	452.06	469.69	425.23	449.01	485.12	437.56	448.44	475.06
424.19	434.40	469.68	439.63	474.13	479.96	447.24	473.35	484.33
411.96	432.38	464.02	440.42	457.50	483.00	467.33	458.73	491.32
422.20	479.72	465.78	417.17	443.31	458.54	446.41	459.58	523.46
414.19	435.75	482.56	426.26	491.83	458.54	425.69	452.31	482.69
419.38	446.94	455.65	448.78	460.45	486.96	448.65	460.93	483.54
406.35	433.41	473.58	434.10	447.76	491.81	435.33	466.62	487.25
410.62	444.30	449.51	421.21	421.71	487.81	436.18	496.16	477.70

much greater than the table value of 3.00. It can be assumed then that there is a significant difference between at least two of the three levels of engine cost.

The same analysis was used to assess the significance of the different levels of shop visit rate. The Null hypothesis was:

> H_o: Are the effects of factor D significant

and the decision rule was:

> If $F > F_{\alpha/2\,(K-1)\,(N-K)}$ (where K is the total number of levels and N is the number of observations) then there is a significant difference in at least two of the three levels.

If $\alpha/2 = .05$, $K-1 = 2$, and $N-K = 261$ then the F Table value, $F_{.05,\ 2,\ 261} = 3.00$

For shop visit rate the ANOVA calculated an F Value of 96.243, again much higher than 3.00 indicating that there was a significant difference between at least two of the three levels.

The last assessment was an analysis of interaction between A and D.

The hypothesis for this test was:

> H_o: Are the interaction effects of A and D significant

with a decision rule:

> If $F > F_{\alpha/2\,(K-1)\,(N-K)}$ (where K is the total number of levels and N is the number of observations) then there is a significant difference in at least two of the three levels.

If $\alpha/2 = .05$, $K-1 = 4$, and $N-K = 261$ then the F Table value

$F_{.05,\ 4,\ 261} = 2.37$

The value calculated by the Two Way ANOVA is 0.147, and is less than the table value indicating that there was no significant difference between any of the levels of interaction of the two factors. It can be assumed therefore, that the interaction effects of A and D are not significant. The computer results of the SPSS Two Way ANOVA for engine cost and shop visit rate are shown in Figure 4-8.

```
* * * * * * * * * * * A N A L Y S I S   O F   V A R I A N C E * * * * * * * * * * *
                 COST
            BY   ENG
                 SVR
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
```

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
MAIN EFFECTS	127839.286	4	31959.821	208.129	0.000
ENG	98281.547	2	49140.773	320.015	0.000
SVR	29557.739	2	14778.870	96.243	0.000
2-WAY INTERACTIONS	90.230	4	22.558	0.147	0.964
ENG SVR	90.230	4	22.558	0.147	0.964
EXPLAINED	127929.516	8	15991.189	104.138	0.000
RESIDUAL	40078.608	261	153.558		
TOTAL	168008.124	269	624.566		

```
    270 CASES WERE PROCESSED.
      0 CASES (  0.0 PCT) WERE MISSING.
```

Figure 4-8 Two Way ANOVA Results

Knowing that at least two of the three levels of each factor are significantly different, the next logical step was to assess exactly how many levels of each factor are in fact different. This is done using an SPSS Oneway ANOVA with a

Duncan's Multiple Ranges a posteriori analysis of means. The Duncan's analysis operates as follows:

1. All means are ranked in ascending order.

2. Using the mean square error, the number of levels and the total number of observations, comparison factors are calculated by the SPSS program.

3. The comparison factors are used to decide if there is a significant difference between adjoining means and then between groupings.

The results for the SPSS analysis of the engine cost and SVR factors are found in Figure 4-9.

Engine Cost Homogeneous Groups

Group 1	Group 2	Group 3
429.2356	452.3244	475.9681

SVR Homogeneous Groups

Group 1	Group 2	Group 3
439.1870	453.5942	464.7469

Figure 4-9 SPSS Analysis of Engine Cost Factors

All homogeneous groups are indicated by underscored lines. As shown in Figure 4-9, no two groups are associated with a single underscore which indicates that, in fact, none of the levels for engine cost or SVR are homogeneous and are assumed to be significantly different.

A similar analysis was accomplished for the shop visit rate with the same results. All three levels were found to be significantly different.

The results of the sensitivity analysis section indicate that changes in the two primary policy parameters

due to either negotiation or improvement in operations and support will significantly effect the overall cost of operating the system.

SPO analysts now know which factors are most important and have a feel for what the system will do when the levels of these factors are changed. This knowledge of the primary factors and their characteristic effects on the system output allow negotiators to effectively negotiate specific factors at their optimum levels.

Once the sensitivity of the model was assessed and the analyst is aware of the most critical policy parameters, it is possible to incorporate this pertinent information into the negotiation process.

Decision Support System

The decision support system is designed to analyze the cost effectiveness of a warranty contract proposal. It uses both the short and long model versions to analyze engine operation and support costs for the warranty period as well as the cost effectiveness of the warranty over the entire life of the engine.

Using vendor supplied component failure probabilities and component replacement costs, SPO analysts can use the short version to compare the up front warranty cost to the anticipated support costs incurred over the warranty period.

On the other hand, the long version analyzes the long term effects of contractor improvements. That is, contractor

made improvements during the warranty period are expected to reduce system operating costs over the operational life cycle.

In Figure 4-10, both versions of the model are integrated in the complete DSS. The short version simulates engine O&S over the warranty period. The output goes directly to a file and prints monthly statistics of unit failure and repair costs.

The long version, with and without warranty input data, simulates engine O&S over a 20 year period. The year end statistics from a simulation of each input data set are filed, averaged, and compared, to provide an analysis of the cost effectiveness of the warranty.

With both model versions incorporated into the DSS, SPO analysts have the needed capability to analyze the short and long term effects of the warranty. To demonstrate this capability, a scenario of the contracting process was developed.

Short Term Warranty Analysis. In this hypothetical case, the contractor has proposed a four year contract in which he will warrant all engine SRU and LRU components against failure, and repair or replace those units at his own expense. He also guarantees that unit failure probabilities will not fall below specific values. The up front cost to the government for this four year warranty is set at $50,000,000.

YZ analysts would use contractor supplied estimates of LRU and SRU component failure probabilities and replacement

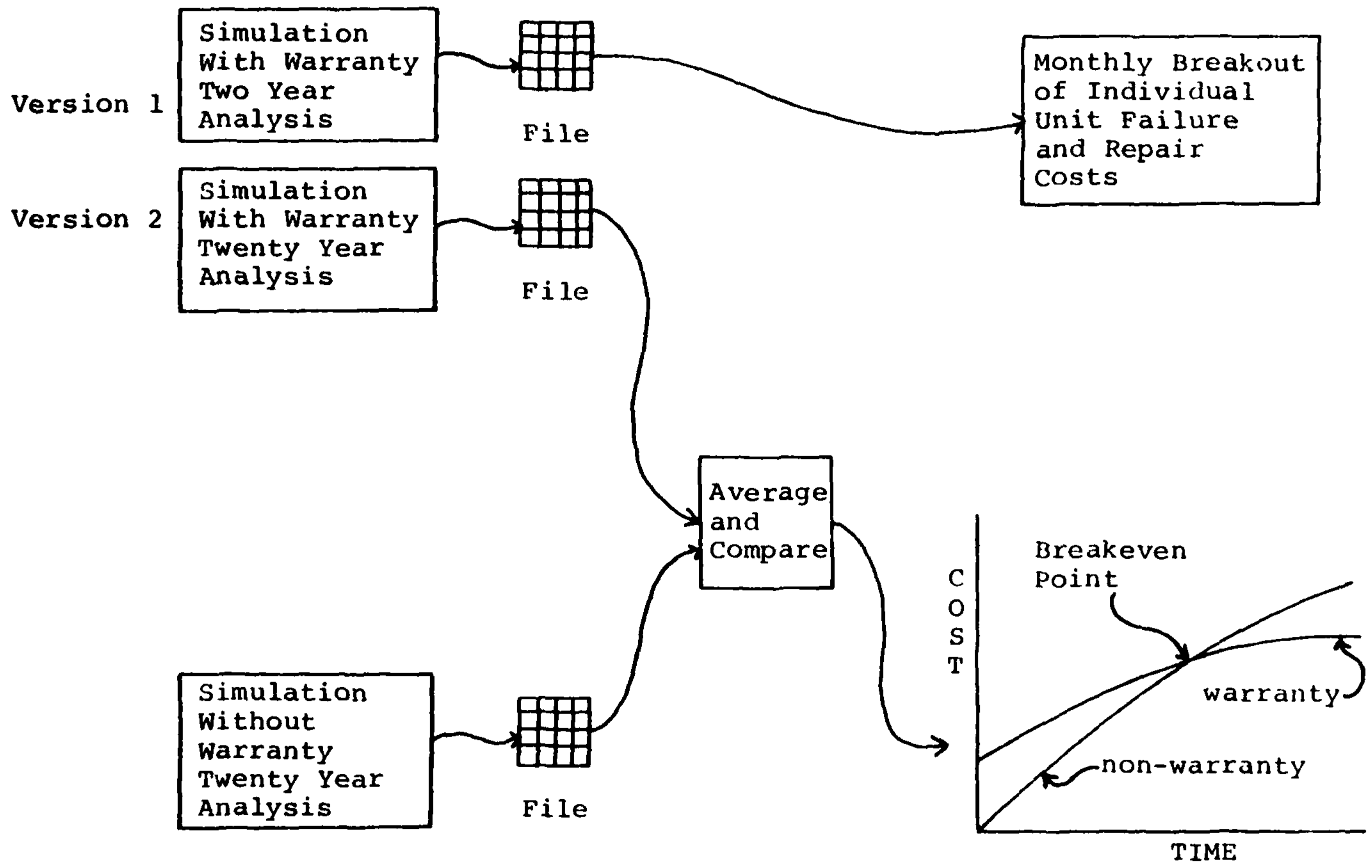


Figure 4-10 Engine Warranty DSS

costs to determine if the warranty is indeed a good investment. They would carefully analyze each LRU and SRU failure rate and replacement cost and then input these values into the short term warranty model.

The construction of the data sets used in the short term model for the four year simulation was done in accordance with the short term users manual provided in Appendix G. The data sets used in this example are shown in Figures 4-11 and 4-12.

```
75#29-SE P-82
76#FXXX 4 2.5 6500000 1.0 .0 0
77#600000  2500000  30000000  2500000
78#29 50 3.28 24 35 59 500
79#4 5 5 51 19 30 30 78
80#4000 160 50 .05 .05
81#25 91.26 2 50 9 1
82#.10 .80 .10
83#46
84#0 0 1 0 0 0 0 0 0 1 1
85#0 1 1 1 2 2 2 2 2 2 3 3
87#4 4 4 4 4 4 4 4 4 4 4 4
88#4 4 4 4 4 4 4 0 0 0 0 0
89#5
90#36 28 18 18 999
91#1
```

Figure 4-11 Short Term Model Data Sets

Ten simulation runs were made and the output data was collected and summarized in Table 4-12.

The results of the four year warranty simulation for each year are graphed in Figure 4-13 and show the warranty cost to exceed the projected repair and replacement costs.

```
290#20
300#FAN-ROTOR 31.62 82.73 60.0 284.94 65.73 78.0 155953.0 .02
310#FAN-STATOR 232.14 86.07 70.0 58.03 54.82 102.25 123056.0 .05
320#FRONT-FRAME 223.6 27.0 80.0 55.89 16.4 90.6 99245.0 .02
330#INLET-GEARBX 82.14 32.0 10.4 82.14 25.88 16.52 7719.0 .05
340#FAN-FRAME 127.67 92.94 70.0 31.92 78.72 84.22 68141.0 .01
350#ACC-GEARBX 98.32 47.45 85.0 98.29 29.95 102.5 59949.0 .01
360#COMP-ROTOR 37.87 304.52 70.0 341.06 235.95 139.57 197063.0 .02
370#FWD-CP-STAT 171.58 281.02 50.0 171.59 211.13 119.89 164595.0 .05
380#AFT-CP-STAT 117.73 252.9 75.0 117.73 198.54 131.36 36281.0 .04
390#COMBUSTOR 90.37 64.12 87.0 809.72 55.55 96.57 48089.0 .35
400#COMP-CASE 65.74 187.22 60.0 262.67 174.15 73.57 54401.0 .01
410#HPT-ROTOR 87.79 121.3 50.0 788.64 81.54 90.76 236608.0 .01
420#HPT-STATOR 698.26 67.9 40.0 77.54 58.26 50.84 167904.0 .02
430#HPT-SHROUD 729.93 98.42 2.0 81.1 73.05 26.27 49111.0 .11
440#LPT-ROTOR 51.26 109.3 72.0 461.04 76.46 105.84 134517.0 .03
450#STG1-LPT-ST 257.52 79.35 80.0 386.4 53.53 105.82 69555.0 .07
460#STG2-LPT-ST 227.55 137.05 25.0 340.95 93.09 69.16 50957.0 .11
470#TURBINE-FRM 146.77 262.0 60.0 342.47 155.0 168.0 57378.0 .01
480#AUGMENTOR 232.32 125.9 70.0 25.81 83.5 113.6 180028.0 .08
490#EXHAUST-NOZ 105.31 192.55 40.0 11.69 114.81 117.74 271349.0 .04
120#16
130#ENGINE-CONTR 417.7 1.6 9.0 70.0 77699.0 .01
140#FUEL-PUMP 138.2 0.4 4.0 18.0 13491.0 .05
150#FAN-SPEED-SE 5.5 0.2 2.8 8.0 2573.0 .05
160#AFT-CONTROL 340.25 1.2 5.0 44.0 60516.0 .05
170#AUG-IG-PLUG 1109.88 0.3 1.5 6.5 1713.0 .90
180#T48-PYROM 77.41 0.5 4.0 7.5 7716.0 .05
190#AUG-FUEL-CTR 70.11 1.5 5.0 35.0 39980.0 .02
200#HYD-PUMP 245.22 0.6 4.0 30.0 37054.0 .05
210#LUBE-PUMP 189.47 1.0 2.0 22.0 12127.0 .05
220#ANTI-ICING 110.72 0.5 3.0 17.0 10593.0 .05
230#FAN-DIS-T2.5 67.9 0.3 2.0 11.0 6667.0 .90
240#FAN-INLET-T2 22.02 0.2 1.0 6.0 2354.0 .90
250#INLET-GUIDE 1329.79 0.0 0.5 1.0 722.0 .10
260#ALTERNATOR 133.62 0.6 3.0 8.0 2653.0 .05
270#FLAME-DET 129.58 0.2 2.0 7.0 2309.0 .04
280#AUG-FUEL-PU. 305.25 1.2 4.0 20.0 25387.0 .05
```

Figure 4-12 Short Term Model Data Sets

TABLE 4-12

Short Version Warranty Output Data

	1	2	3	4	5	6	7	8	9	10
SRU Repair	13.35	11.90	12.29	12.70	12.52	13.69	11.70	13.43	12.07	12.36
LRU Repair	1.01	0.94	1.16	1.06	1.10	1.11	1.06	1.09	1.16	1.11
SRU Replace	8.89	8.71	8.04	8.82	8.63	7.57	8.15	8.50	6.64	7.96
LRU Replace	0.55	0.69	0.83	0.74	0.73	0.63	0.52	0.64	0.75	0.81
Total*	23.81	22.24	22.33	23.[illegible]1	22.97	23.00	21.42	23.66	20.61	22.2[illegible]

*Differences in totals due to rounding.
Costs presented in millions.

Thus over the four year warranty period, the projected replacement costs are much less than the $50,000,000 warranty cost.

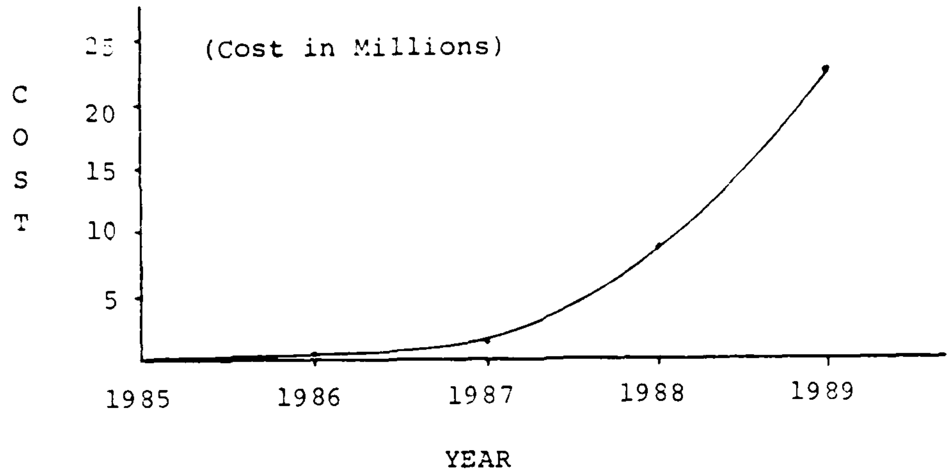


Figure 4-13 Short Term Four Year Warranty Plot

SPC analysts and negotiators now have an estimate of the short term cost of the proposal and can continue to use the model to negotiate different warranty costs or component failure rates to revise the contract proposal. However, the analysis is not complete until the entire operational life cycle of the system has been considered. It is expected that the contractor will make component reliability improvements during the warranty period to increase his profit margin. Obviously if he has warranted a particular component for a given failure rate and can reduce the failures by increasing the reliability, he replaces fewer components and realizes a better profit.

These reliability improvements, however, will continue to save repair and replacement costs beyond the end of the warranty period when the government is incurring those costs. Thus to fully analyze how cost effective a warranty is, the operational life of the engine must be analyzed. The second or long term warranty model version is used to analyze the effects of component reliability improvement over the life of the system.

Long Term Warranty Analysis. The second version of the warranty model analyzes the effect of component reliability improvement over a 20 year period. YZ analysts used data sets that were similar to those used in the short version for analysis of the extended effects of the warranty. The long term users guide, in Appendix F, was used to develop these data sets. However, to determine if the warranty is cost effective, SPO analysts must also construct non-warranty input parameter data sets whose output is used as a comparison to the warranty results. Ten simulation runs of the warranty and non-warranty parameter sets were made with the results shown in Tables 4-13 and 4-14.

The average accumulated yearly costs for both the warranty and non-warranty simulations over the twenty years are plotted in Figure 4-14.

The graph shows the breakeven point at the eleven year point of system life. By observation it appears that the engine warranty is cost effective at that point in the

TABLE 4-13 Long Version Warranty Output Data

	1	2	3	4	5	6	7	8	9	10	Ave
1985	114.48	121.59	122.03	114.50	121.68	120.98	121.85	121.13	114.64	121.30	119.42
1986	146.12	146.19	154.00	166.17	146.08	146.72	145.84	144.87	160.03	151.82	150.78
1987	262.97	289.06	263.79	257.96	276.34	279.75	256.89	250.42	270.84	249.19	265.74
1988	335.13	349.09	361.97	361.87	375.20	254.99	401.34	357.78	361.06	352.80	361.12
1989	396.71	396.22	377.41	392.74	395.41	584.12	418.94	391.15	389.53	399.18	394.24
1990	411.85	413.56	398.94	404.67	424.02	396.71	434.19	403.86	405.36	413.64	410.77
1991	426.86	425.23	419.37	417.63	438.37	460.72	446.53	417.86	416.85	434.91	430.43
1992	440.50	446.07	432.96	432.05	542.04	472.27	460.76	439.30	429.89	445.81	445.17
1993	480.00	458.55	464.70	446.13	469.37	486.07	475.79	453.72	444.04	460.95	463.92
1994	493.98	472.65	477.30	459.73	483.56	497.48	478.65	466.81	458.87	475.27	476.03
1995	505.64	488.06	492.55	478.14	495.11	511.10	501.66	479.95	471.51	487.40	491.13
1996	521.10	501.10	505.36	492.56	513.75	527.61	516.26	495.09	488.04	499.51	506.04
1997	535.29	515.70	518.61	508.59	525.39	539.99	529.95	506.95	501.32	515.30	519.71
1998	548.44	527.65	531.84	520.67	540.23	553.39	543.35	519.40	514.12	527.63	532.66
1999	562.08	557.40	540.49	533.09	550.95	566.59	555.28	533.70	526.23	540.39	547.02
2000	575.19	568.83	559.43	545.90	566.83	581.14	575.15	544.43	559.54	554.46	563.09
2001	598.83	582.34	574.83	577.15	580.17	595.54	591.59	558.00	574.39	566.22	579.01
2002	602.60	594.68	588.22	588.70	591.32	608.58	602.85	571.31	587.18	578.32	591.38
2003	514.93	607.32	601.20	602.44	602.29	621.85	616.76	585.23	599.90	592.52	604.44
2004	626.12	620.87	611.61	615.84	618.43	636.08	630.56	596.92	613.69	607.42	617.75
2005	640.14	636.64	624.56	630.62	632.04	649.35	643.10	610.89	628.21	620.70	631.63

TABLE 4-14 Long Version Non-Warranty Output Data

	1	2	3	4	5	6	7	8	9	10	Ave
1985	71.51	64.87	72.03	78.13	71.59	57.99	71.61	65.02	72.79	71.56	69.71
1986	117.60	96.59	102.50	104.18	110.52	104.33	96.30	109.33	116.10	116.51	107.40
1987	213.24	224.16	221.82	216.95	224.80	227.53	224.93	208.49	215.31	216.48	219.37
1988	334.77	316.79	314.45	313.71	334.52	310.37	344.13	341.94	321.51	284.20	321.64
1989	369.25	362.10	366.77	352.73	383.04	356.02	368.71	359.10	383.15	369.43	367.03
1990	391.41	380.42	336.59	373.57	402.32	389.62	387.28	374.84	403.47	390.47	387.99
1991	407.63	397.25	405.62	391.42	420.11	418.58	426.28	393.10	427.53	408.55	409.31
1992	455.89	414.53	422.89	428.07	436.70	431.06	444.62	416.07	442.98	428.33	432.11
1993	444.07	433.78	439.95	448.04	454.61	447.59	464.12	459.46	459.71	442.17	449.35
1994	465.74	450.79	460.19	466.08	475.73	463.63	481.69	478.97	477.91	460.13	468.09
1995	495.38	469.87	492.08	485.21	494.52	485.55	498.80	496.48	500.21	505.36	492.35
1996	512.88	488.38	509.91	506.71	509.84	502.25	519.04	515.10	517.60	523.77	510.55
1997	530.32	504.68	530.07	522.18	528.38	518.82	535.48	533.36	537.04	543.01	528.33
1998	545.90	521.73	547.32	540.50	547.46	536.68	554.20	554.07	556.35	561.78	546.60
1999	564.59	538.53	576.21	560.52	565.58	554.94	573.58	570.70	576.83	580.73	565.42
2000	586.67	553.64	583.04	576.24	586.09	573.23	590.63	588.90	592.53	597.35	582.83
2001	602.28	572.57	600.92	596.53	605.37	592.40	606.94	606.10	611.77	616.08	601.09
2002	619.55	617.40	617.78	615.17	620.74	609.84	623.19	623.22	630.77	633.05	621.07
2003	640.33	636.31	619.91	633.85	638.99	628.15	654.98	640.97	646.48	649.45	641.94
2004	657.09	655.00	669.05	651.81	655.82	644.88	672.61	664.23	662.67	672.08	660.52
2005	675.16	671.21	686.64	677.51	675.64	664.86	687.53	683.67	678.70	688.98	678.99

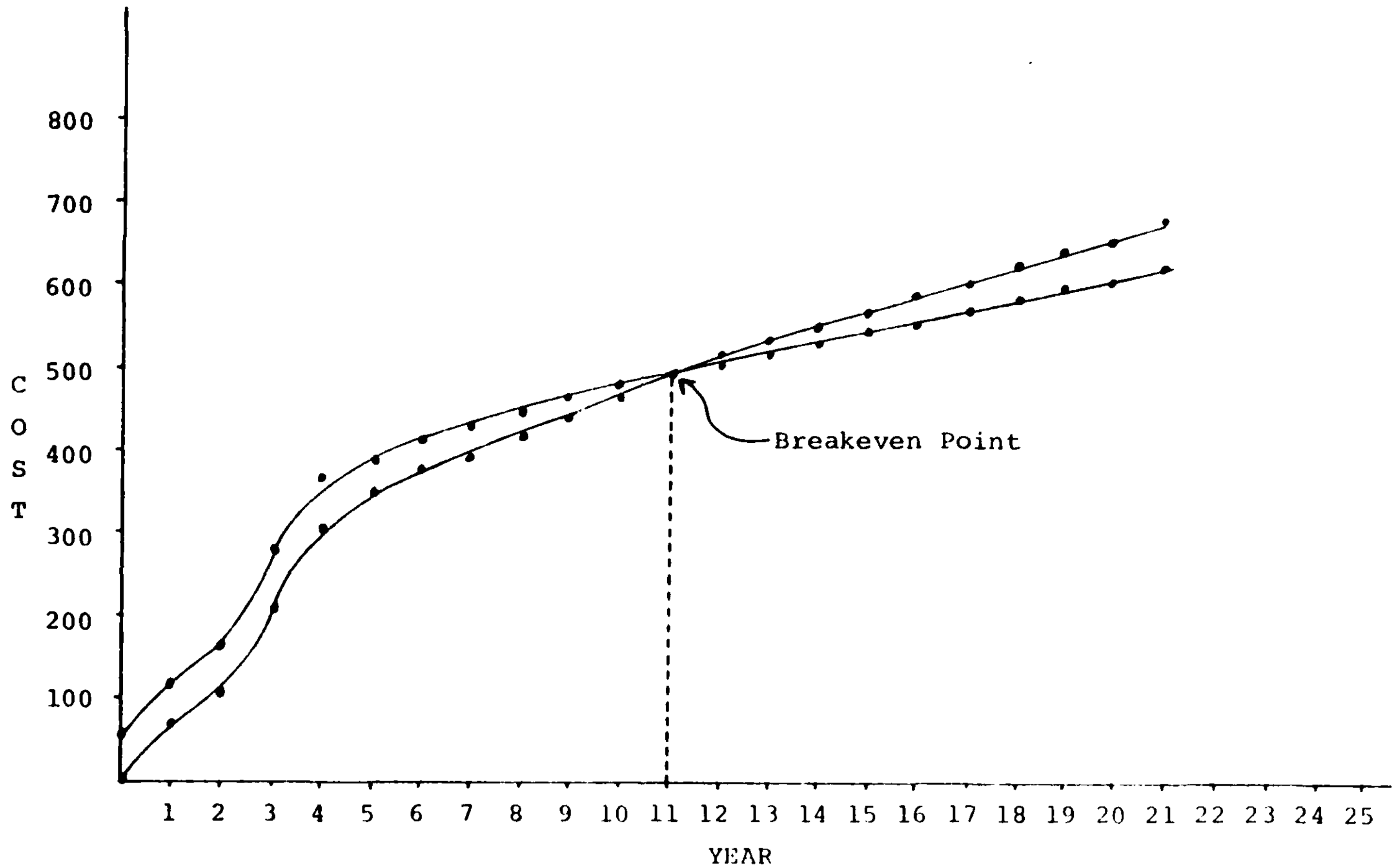


Figure 4-14 Long Term 20 Year Plot

life of the system, however, the crossover point must be further analyzed to determine the actual point in time when the difference between the warranty and non-warranty lines is in fact significant. A small sample T-Test is accomplished at different points prior to the observed breakeven point to determine when the differential of the two lines is no longer significant. For the purpose of this example, the testing began at the first data point prior to the breakeven point, that being the tenth year.

To perform this test, three assumptions need to be validated. First it is assumed that the relative frequency distribution of each sample approximates the normal. Earlier validation testing had shown that the model delivers a normal distribution and the analyst can, therefore, assume normality of the studied populations.

Second, it is assumed that the variances of each of the sampled populations are equal. To test this assumption, the variances were analyzed as follows. The Null hypothesis was:

H_o: The variances are equal

and the alternate hypothesis was

H_a: The variances are not equal

The test statistic for this is a comparison of the F Value which was calculated as follows:

$$F_{\alpha/2,\ N_1-1,\ N_2-1} = 3.18$$

$$\text{where } \alpha = .10,\quad N_1 = 10,\quad N_2 = 10$$

And the decision rule is:

If $F > F_{\alpha/2(N_1-1)(N_2-1)}$ then there is significant difference between the variances.

The results are shown in Figure 4-14 and indicate that the variances are not significantly different.

$$F = \frac{\text{Large Variance}}{\text{Small Variance}} = \frac{166.7}{101.4} = 1.644$$

$$F \not> F_{\alpha/2, N_1-1, N_2-1}$$

The third and final assumption is that the samples are randomly selected. Due to the random nature of the model, the analyst can assume independence.

With the assumptions validated, the actual T-Test may be performed. First the analyst must develop the hypothesis to be tested as follows:

H_o: $\mu_1 = \mu_2$

H_a: $\mu_1 \neq \mu_2$

where μ_1 = the warranty mean

μ_2 = the non-warranty mean

The next step is to develop the T-statistic for testing which is done as follows:

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{S_p^2 \quad \frac{1}{N_1} + \frac{1}{N_2}}}$$

where $\bar{X}_1$ = warranty mean = 476.03

$\bar{X}_2$ = non-warranty mean = 468.09

$N_1 = N_2 =$ 10 samples

$$S_p^2 = \frac{(N_1-1)S_1^2 + (N_2-1)S_2^2}{N_1 + N_2-2} = 134.036$$

where

S_1^2 = 166.7 = variance of warranty

S_2^2 = 101.4 = variance of non-warranty

$t = 1.53$

and since the rejection region is

$$t > t_{\alpha/2, N_1+N_2-2}$$

or

$$1.53 > 1.33$$

the test rejects the Null hypothesis and indicates that there is a significant difference.

This illustrates that the first point in time when the two costs are equal is at the breakeven point. The analyst has strong evidence that the 11 year point is truly the break-even point and beyond that point the $50,000,000 warrant is cost effective.

In this hypothetical case, the use of the long and

short warranty model versions has provided SPO analysts with a decision support system that can evaluate the long and short term effects of warranty. This warranty DSS is a valuable tool needed to assist in the decision making process for engine system procurement under warranty.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The purpose of this thesis was to research and develop a competent decision support system that assesses the turbine engine life cycle cost under warranty. This DSS was requested by the Engine SPO to provide contract specialists with the specific warranty data needed to effectively analyze a warranty proposal during source selection negotiations.

The research design used to construct the decision support tool included first a conceptual study of the turbine engine operating environment. From this study, the researchers developed the engine O&S system warranty model. The model was verified and validated, and then tested for sensitivity to the change in value of five policy parameters. The sensitivity analysis of these parameters provided analysts with insight concerning parameter impact on the O&S system response. The testing proved the model to be a reliable effective tool for analyzing warranty proposals.

Two versions of the warranty model were developed to provide short and long term warranty analysis and both versions were integrated into the total warranty decision support system as a versatile tool designed to assist YZ analysts and contract

specialists evaluate the cost effectiveness of a turbine engine warranty.

Application

The warranty DSS can be used to evaluate warranties from two perspectives. First it examines the short term warranty period, analyzing the cost of operations and providing a breakout of unit repair and replacement costs. This allows YZ analysts to easily assess individual unit costs and compare these costs to specific contractor assurances.

Second, the DSS provides a life cycle approach to warranty analysis. In the long model version component improvements made during the warranty period are analyzed over the life of the engine system to determine their overall cost effectiveness.

These two DSS applications provide a more realistic warranty analysis by evaluating both the near and long term cost and benefits of a warranty.

Recommendation for Future Study

Due to time constraints, five areas of study were either abbreviated or assumed to be true in this research. They are explained below with the understanding that the knowledge gained in each area would further strengthen the already valid simulation model.

The first improvement should be the addition of further mechanization of the system. Computer coding should be designed to accomplish the analysis on the long term

version of the model. The coding should also provide a graphics capability to plot the average cost curves. This mechanization would greatly improve the speed of analysis.

Second, since the warranty model was validated using another model, it should be further assessed for validity using actual engine warranty data when that data becomes available.

Third, a study should be conducted to validate the assumption that improvements will occur due to the application of a warranty. While the model and decision support system assume an improvement occurs, they also show that without that improvement the breakeven point would never occur and the worth of the warranty would be seriously questioned. An assessment of the contractors intentions in warranty application is an area of future study which is highly recommended.

Fourth, there is the need for an analysis model for other possible maintenance concepts. The current model assumes a three level maintenance system. However, several new methods of maintenance management are being attempted and these methods should be included in separate versions of the model.

Finally, model sensitivity should be analyzed for all input parameters. Although five policy parameters were considered most important, other parameters and parametric relationships may also be significant and should be tested for their effects on model output.

APPENDICES

APPENDIX A

PROGRAM LISTING FOR WARR.3

The simulation model contained in this appendix is written in Simscript II.5 and is designed for use on the AFLC Honeywell system. The program is stored in the Create Time Sharing System under the name of WARR.3 and uses data files stored under the names TEST100 and TEST.DAT.

```
10##S :.8,16
20$       IDENT    WP0354,AFIT-LS  HELLESTO     WARR.3
30$       LIMITS  15,40K,,10K
40$       LOWLOAD
50$       OPTION   FORTRAN,NOMAP
60$       LIBRARY SL
70$       PROGRAM RLHS
80$       LIMITS  15,40K,,10K
90$       PRMFL    H*,R,R,CACI/SIM2.5
100$       FILE     *1
110$       FILE     *2
120$       FILE     P*,B1S
130      PREAMBLE
140      NORMALLY MODE IS INTEGER
150      EVENT NOTICES INCLUDE
160        DEPLOYMENT,
170        ENGINE.REPAIR,
180        INSPECTION,
190        TCTO,
200        SCHED.TCTO,
210        END.OF.MO.STATS,
220        REPORT
230        EVERY INTER.REPAIR HAS AN PART
240        EVERY DEPOT.REPAIR HAS AN ITEM
250      DEFINE SPARE.CHECK AS A ROUTINE WITH 1 VALUE
260      DEFINE ICOUNT,ERCNT,LRUCNT,SCNT1,SCNT2,MAX,LCNT,SCNT
270        AS VARIABLES
280      DEFINE YR.START,YR.REPORT,YR.TCTO,MO.QUIT,YR.BEG AS REAL VARIABLES
290      DEFINE ECNT,FHT,IMO,FHP,INFRED AS VARIABLES
300      DEFINE LRATE,ORG.HRS,INT.HRS,DEP.HRS,ENG.COST,EOH.HRS,TOT.COST,TIN.COST,
310       RFAC,MIL,ORATE,IRATE,DRATE,INFLAT,FIN.COST,DISC AS REAL VARIABLES
320      DEFINE SIRATE,SDRATE,SI.TOT,SD.TOT,SI.PER AS REAL VARIABLES
330      DEFINE PLANES,ENGS,B.TRANS,ETCOST,STCOST,LTCOST AS VARIABLES
340      DEFINE OCOST,ICOST,DCOST,ECOST,PSPARES,CSPARES AS VARIABLES
350      DEFINE LPSPARES,LCSPARES,SE.O,SE.I,SE.D,WARR,PMW AS VARIABLES
360      DEFINE TE,TL,TS,ELTIME,EBTIME,SOTIME,SBTIME,LDTIME AS VARIABLES
370      DEFINE SVR,ER.PROB,IMAN,OVER.PER,PDAYS,WARR.COST AS REAL VARIABLES
380      DEFINE PQ, EREM,LRUREM,SRUREM AS A 1-DIMENSIONAL ARRAY
390      DEFINE EALL,EDEP,SPEC,ETCTO,LRUS,SRUS,DHRS,EBUY AS 1-DIMENSIONAL ARRAYS
400      DEFINE XEALL,XEDEP,XSPEC,XETCTO,XLRU,XSRU,XDHRS,XEBUY AS VARIABLES
410      DEFINE IS.HRS,DS.HRS,OL.HRS,IL.HRS,DL.HRS AS REAL VARIABLES
420      DEFINE LRUPROB,SRUPROB,CON.FAC AS 1-DIMENSIONAL REAL ARRAYS
430      DEFINE SCOST,LCOST,SE.COST,EFAIL AS 1-DIMENSIONAL REAL ARRAYS
440      DEFINE LRU.HRS, SRU.HRS,RESULT AS 2-DIMENSIONAL REAL ARRAYS
450      DEFINE CONDEMS,LEVEL,SPARES,BASEQTY,SE.RQMT AS 1-DIMENSIONAL ARRAYS
460      DEFINE PRGM AS A ALPHA VARIABLE
470       DEFINE SEED,SED,SIM,ST AS INTEGER VARIABLE
480      END
```

```

    MAIN
    RESERVE LRUPROB,SRUPROB AS 30
    RESERVE LRUREM,SRUREM,SCOST,LCOST AS 30
    RESERVE PQ AS 132    RESERVE EREM AS 6
    RESERVE BASEQTY AS 30     RESERVE SE.RQMT,SE.COST,EFAIL AS 3
    RESERVE LRU.HRS AS 3 BY 30
    RESERVE SRU.HRS AS 4 BY 30
    RESERVE RESULT AS 4 BY 30
    RESERVE EALL.EDEP,SPEC,ETCTO,LRUS.SRUS,DHRS.EBUY AS 250
    RESERVE LEVEL,SPARES,CON.FAC,CONDEMS AS 50
    DEFINE NAME AS A 1-DIMENSIONAL ALPHA ARRAY  RESERVE NAME AS 2
    DEFINE DATE AS A 1-DIMENSIONAL ALPHA ARRAY     RESERVE DATE AS 2
''-----------------------------------------------------------
    READ DATE(1),DATE(2)
    READ PRGM,ECNT,SVR,ENG.COST,RFAC,OVER.PER,WARR,PMW
    LET SVR = SVR * RFAC
    READ SE.COST(1),SE.COST(2),SE.COST(3),WARR.COST
    READ FHP,INFREQ,IMAN,ORATE,IRATE,DRATE,EDM.HRS
    LET ER.PROB = SVR * ECNT * INFREQ / 1000
    READ TE,TL,TS,EDTIME,EBTIME,SDTIME,SBTIME,LDTIME
    READ ETCOST,STCOST,LTCOST,INFLAT,DISC
    READ YR.START,YR.REPORT,YR.TCTO,MO.QUIT,SEED.SED,SIM,ST
    LET YR.BEG = YR.START
    READ EFAIL(1),EFAIL(2),EFAIL(3)
    READ MAX  FOR I = 1 TO MAX READ PQ (I)
    LET CY = YR.START    LET J = 1
    FOR K = 1 TO ((MAX + 11) / 12) DO
      LET JJ = J + 11
    FOR I = J TO JJ ADD PQ (I) TO TOT
    FOR I = J TO JJ
       ADD TOT TO TOTAL  LET TOT = 0
    LET CY = CY + 1  LET J = J + 12
   LOOP
    READ NO.OF.BASES   FOR I = 1 TO NO.OF.BASES READ BASEQTY (I)
    READ CIRF
    FOR I = 2 TO NO.OF.BASES LET BASEQTY(I) = BASEQTY(I) + BASEQTY(I-1)
    LET B = 1   LET SE.RQMT (2) = 1
     ' SRU DATA - - - - - - - - - - - - - - - - - - - - -
    READ SCNT     FOR I = 1 TO SCNT  DO
    READ NAME(1),NAME(2),SIRATE,SRU.HRS(1,I),SRU.HRS(2,I),
      SDRATE,SRU.HRS(3,I),SRU.HRS(4,I),SCOST(I),CON.FAC(I)
    LET SIRATE=SIRATE*1.00
    LET SDRATE=SDRATE*1.00
    LET SRU.HRS(1,I)=SRU.HRS(1,I)*1.00
    LET SRU.HRS(2,I)=SRU.HRS(2,I)*1.00
    LET SRU.HRS(3,I)=SRU.HRS(3,I)*1.00
    LET SRU.HRS(4,I)=SRU.HRS(4,I)*1.00
    LET SRUPROB(I) = RFAC * (SIRATE + SDRATE) / (EFAIL(2) * SVR * 1000)
    LET SI.TOT = SI.TOT + SIRATE     LET SD.TOT = SD.TOT + SDRATE
  LOOP
```

```
LET SI.PER = SI.TOT / (SI.TOT + SD.TOT)
   LRU DATA - - - - - - - - - - - - - - - - - - - - -
READ LCNT   FOR I = 1 TO LCNT  DO
READ NAME(1),NAME(2),LRATE.LRU.HRS(1,I),LRU.HRS(2,I),LRU.HRS(3.I),
  LCOST(I),CON.FAC(I+SCNT)
LET LRATE=LRATE*1.00
LET LRU.HRS(1,I)=LRU.HRS(1,I)*1.00
LET LRU.HRS(2,I)=LRU.HRS(2,I)*1.00
LET LRU.HRS(3,I)=LRU.HRS(3,I)*1.00
LET LRUPROB (I) = (LRATE * ECNT * INFREQ) / 1000000
LOOP
 ''- - - SCHEDULE INSPECTIONS AND DEPLOYMENTS - - - - - - - - - -
 FOR I = 1 TO MAX  DO
 IF PQ (I) = 0 JUMP AHEAD  ELSE
 LET PDAYS = 30.42 / PQ (I)
 FOR J = 1 TO PQ(I) SCHEDULE AN INSPECTION IN
   (PDAYS * J) + (30.42 * (I - 1)) + ((INFREQ / FHP) * 30.42) DAYS
 FOR J = 1 TO PQ (I)
  SCHEDULE A DEPLOYMENT IN (PDAYS * J) + 30.42 * (I -1) DAYS
HERE  LOOP
 SCHEDULE A REPORT IN YR.REPORT  DAYS
 SCHEDULE A END.OF.MO.STATS IN 30.41 DAYS
 SCHEDULE A SCHED.TCTO IN 366 * YR.TCTO DAYS
 CALL ORIGIN.R(1,1,YR.START)
 START SIMULATION
 END
```

```
ROUTINE FOR INITIALIZATION
LET TIME.V=0.00
LET SIM=SIM+1
IF SIM=31
  LET SEED=1
  LET SED=10
  JUMP AHEAD
  ELSE
IF SIM=21
    LET SEED=1
    LET SED=10
  JUMP AHEAD
  ELSE
IF SIM=11
    LET SEED=1
    LET SED =9
ALWAYS  HERE
LET SEED=SEED+1
LET YR.START=YR.BEG  LET IMO=1  LET PLANES=0
LET ENGS=0  LET B=1  LET SE.RQMT(2)=1
LET ICOUNT=0  LET FHT=0 LET DRG.HRS=0
LET ERCNT=0  LET EREM(1)=0  LET EREM(2)=0
LET DEP.HRS=0  LET EREM(3)=0   LET EREM(4)=0
LET TRANS=0  LET SCNT1=0  LET SCNT2=0
LET INT.HRS=0  LET IS.HRS=0  LET DS.HRS=0
LET EREM(5)=0  LET LRUCNT=0  LET OL.HRS=0
LET IL.HRS=0  LET DL.HRS=0   LET LEVEL(50)=0
LET EREM(6)=0  LET TOT.COST=0  LET TIN.COST=0
LET FIN.COST=0   LET SPARES(50)=0
FOR I=1 TO LCNT DO
  LET LRUREM(I)=0
LOOP
FOR I=1 TO SCNT DO
  LET SRUREM(I)=0
LOOP
FOR I=1 TO LCNT+SCNT DO
  LET LEVEL(I)=0
  LET SPARES(I)=0
  LET CONDEMS(I)=0
LOOP
```

```
''- - - SCHEDULE INSPECTIONS AND DEPLOYMENTS - - - - - - - - - - -
FOR I = 1 TO MAX  DO
IF PQ (I) = 0 JUMP AHEAD  ELSE
LET PDAYS = 30.42 / PQ (I)
FOR J = 1 TO PQ(I) SCHEDULE AN INSPECTION IN
  (PDAYS * J) + (30.42 * (I - 1)) + ((INFREQ / FHP) * 30.42) DAYS
FOR J = 1 TO PQ (I)
 SCHEDULE A DEPLOYMENT IN (PDAYS * J) + 30.42 * (I -1) DAYS
HERE  LOOP
SCHEDULE A REPORT IN YR.REPORT  DAYS
SCHEDULE A END.OF.MO.STATS IN 30.41 DAYS
SCHEDULE A SCHED.TCTO IN 366 * YR.TCTO DAYS
IF SIM<ST RETURN ELSE

STOP END
```

```
EVENT DEPLOYMENT
ADD 1 TO PLANES   ADD ECNT TO ENGS
IF PLANES > BASEQTY (B) ADD 1 TO SE.RQMT (2) ADD 1 TO B
ALWAYS  RETURN  END
```

```
    EVENT INSPECTION
    DEFINE SFAC AS A REAL VARIABLE    LET SFAC = 1.0
    ADD 1 TO ICOUNT   ADD ECNT * INFREQ TO FHT
    ADD IMAN TO ORG.HRS
    LET TO = 0   IF RANDOM.F(SED) < OVER.PER  LET TO = 10  ALWAYS
    '' CHECK FOR AN ENGINE REMOVAL
    IF RANDOM.F(SED) < ER.PROB GO TO 'REMOVE.ENG' ELSE GO TO 'CHECK.LRU'
'REMOVE.ENG'
    ADD 1 TO ERCNT    ADD 55 TO ORG.HRS
    DEFINE X AS A REAL VARIABLE  LET X = RANDOM.F(SEED)
    IF X < EFAIL(1) GO TO 'MAJOR.DAMAGE'  ELSE
    IF X > EFAIL(1) AND X < (1 - EFAIL(3)) GO TO 'SRU.CAUSED'
      ELSE GO TO 'LRU.CAUSED'
'MAJOR.DAMAGE'
    ADD 1 TO EREM(1)     ADD EOH.HRS TO DEP.HRS
    ADD ETCOST TO TRANS   ADD 10 TO ORG.HRS  ''PACK ENGINE
    SCHEDULE AN ENGINE.REPAIR IN TO + TE + EDTIME + TE DAYS
    PERFORM SPARE.CHECK(50)     GO TO 'CHECK.LRU'
'LRU.CAUSED'
    ADD 1 TO EREM(2)   ADD 46 TO INT.HRS
    SCHEDULE AN ENGINE.REPAIR IN 15 DAYS
    PERFORM SPARE.CHECK(50)    GO TO 'CHECK.LRU'
'SRU.CAUSED'
    ADD 1 TO EREM(3)
    SCHEDULE AN ENGINE.REPAIR IN EBTIME DAYS
    PERFORM SPARE.CHECK(50)
    IF RANDOM.F(SEED) > SI.PER GO TO 'DEPOT.REPAIR.OF.SRU'  ELSE
'IREPAIR.OF.SRU'
    ADD 1 TO EREM(4)      ADD LTCOST TO TRANS '' COMPONENT
    FOR I = 1 TO SCNT   DO
     IF RANDOM.F(SEED)  < SRUPROB(I)
       ADD 1 TO SRUREM (I)    ADD 1 TO SCNT1
       ADD SRU.HRS(1,I) * SFAC TO INT.HRS
       ADD SRU.HRS(1,I)*SFAC TO IS.HRS
       LET SFAC = .6
       ADD SRU.HRS(2,I) TO DEP.HRS
       ADD SRU.HRS(2,I) TO DS.HRS
       SCHEDULE A INTER.REPAIR(I) IN SBTIME DAYS
       PERFORM SPARE.CHECK(I)
    ALWAYS  LOOP     GO TO 'CHECK.LRU'
'DEPOT.REPAIR.OF.SRU'
    ADD 1 TO EREM(5)    ADD STCOST TO TRANS
```

```
    FOR I = 1 TO SCNT   DO
     IF RANDOM.F(SEED) < SRUPROB(I)
       ADD 1 TO SRUREM (I)     ADD 1 TO SCNT2
       ADD SRU.HRS(3,I) * SFAC TO INT.HRS
       ADD SRU.HRS(3,I)*SFAC TO IS.HRS
       LET SFAC = .6
       ADD SRU.HRS(4,I) TO DEP.HRS
       ADD SRU.HRS(4,I) TO DS.HRS
       SCHEDULE A DEPOT.REPAIR(I) IN TO + TS + 10 + SDTIME + TS DAYS
      PERFORM SPARE.CHECK(I)
    ALWAYS   LOOP
'CHECK.LRU'
     '' CHECK FOR AN LRU FAILURE
    FOR I = 1 TO LCNT   DO
      IF RANDOM.F(SEED) < LRUPROB (I) ADD 1 TO LRUCNT
       ADD 1 TO LRUREM (I)      ADD LTCOST TO TRANS
       ADD LRU.HRS(1,I) TO ORG.HRS
       ADD LRU.HRS(1,I) TO OL.HRS
       ADD LRU.HRS(2,I) TO INT.HRS
       ADD LRU.HRS(2,I) TO IL.HRS
       ADD LRU.HRS(3,I) TO DEP.HRS
       ADD LRU.HRS(3,I) TO DL.HRS
       LET II = I + SCNT
       SCHEDULE A DEPOT.REPAIR (II) IN TO + TL + LDTIME + TL DAYS
      PERFORM SPARE.CHECK(II)
      ALWAYS
    LOOP
  HERE
    SCHEDULE AN INSPECTION IN (INFREQ / FHP) * 30.42 DAYS
    RETURN END
```

```
    EVENT INTER.REPAIR(PART)
    IF RANDOM.F(SEED) > (CON.FAC(PART)*1.00) ADD 1 TO LEVEL(PART)
    JUMP AHEAD
      ELSE  ADD 1 TO CONDEMS (PART)
   HERE  RETURN END

    EVENT DEPOT.REPAIR(ITEM)
    IF RANDOM.F(SED) > (CON.FAC(ITEM)*1.00) ADD 1 TO LEVEL(ITEM)
    JUMP AHEAD
      ELSE  ADD 1 TO CONDEMS (ITEM)
   HERE  RETURN END

    EVENT ENGINE.REPAIR
    ADD 1 TO LEVEL(50)
    RETURN  END

    SUBROUTINE SPARE.CHECK(NUM)
    SUBTRACT 1 FROM LEVEL(NUM)
    IF NUM = 50 GO TO 'ENG.LOGIC'  ELSE
    IF NUM > SCNT GO TO 'LRU.LOGIC'  ELSE
'SRU.LOGIC'
    IF LEVEL(NUM) < 0  ADD 1 TO SPARES(NUM)  ADD 1 TO LEVEL (NUM)
     ALWAYS  JUMP AHEAD
'ENG.LOGIC'
    IF LEVEL(50) < B / 2 ADD 1 TO SPARES(NUM)  ADD 1 TO LEVEL(NUM)
      ALWAYS  JUMP AHEAD
'LRU.LOGIC'
    IF LEVEL(NUM) < B / 2 ADD 1 TO SPARES(NUM)  ADD 1 TO LEVEL(NUM)
      ALWAYS  HERE  RETURN  END

    EVENT TCTO
    ADD 1 TO EREM(6)
    SCHEDULE AN ENGINE.REPAIR IN 7 DAYS
      PERFORM SPARE.CHECK(50)
    RETURN  END

    EVENT SCHED.TCTO
    LET TCNUM = ENGS - (12*EALL(IMO))
    FOR I = 1 TO TCNUM  SCHEDULE A TCTO IN (360 / TCNUM) * I DAYS
    SCHEDULE A SCHED.TCTO IN 365 * YR.TCTO DAYS
    RETURN  END
```

```
EVENT END.OF.MO.STATS
ADD 1 TO IMO
IF IMO = 1
  LET EALL(1) = ERCNT     LET EDEP(1) = EREM(1)
  LET SPEC(1) = ICOUNT    LET ETCTO(1) = EREM(6)
  LET LRUS(1) = LRUCNT    LET SRUS(1) = SCNT1 + SCNT2
  LET DHRS(1) = DEP.HRS   LET EBUY(1) = SPARES(50)
 JUMP AHEAD   ELSE
LET EALL(IMO) = ERCNT - XEALL
LET EDEP(IMO) = EREM(1) - XEDEP
LET SPEC(IMO) = ICOUNT - XSPEC
LET ETCTO(IMO) = EREM(6) - XETCTO
LET LRUS(IMO) = LRUCNT - XLRU
LET SRUS(IMO) = SCNT1 + SCNT2 - XSRU
LET DHRS(IMO) = DEP.HRS - XDHRS
LET EBUY(IMO) = SPARES(50) - XEBUY
HERE  SCHEDULE A END.OF.MO.STATS IN 30.42 DAYS
LET XEALL = ERCNT     LET XEDEP = EREM(1)
LET XSPEC = ICOUNT    LET XETCTO = EREM(6)
LET XLRU = LRUCNT     LET XSRU = SCNT1 + SCNT2
LET XDHRS = DEP.HRS    LET XEBUY = SPARES(50)
LET ECOST = SPARES(50) * ENG.COST
FOR I = 1 TO SCNT
  LET PS = PS + ((SPARES(I) - CONDEMS(I)) * SCOST(I))
  LET PSPARES = PS
  LET PS = 0
FOR I = 1 TO SCNT
  LET CS = CS + (CONDEMS(I) * SCOST(I))
  LET CSPARES = CS
  LET CS = 0
FOR I = 1 + SCNT TO SCNT + LCNT
  LET LPS = LPS + ((SPARES(I) - CONDEMS(I)) * LCOST(I - SCNT))
  LET LPSPARES = LPS
  LET LPS = 0
FOR I = 1 + SCNT TO SCNT + LCNT
  LET LCS = LCS + (CONDEMS(I) * LCOST(I - SCNT))
  LET LCSPARES = LCS
  LET LCS = 0
LET OCOST = ORG.HRS * ORATE
LET ICOST = INT.HRS * IRATE
LET DCOST = DEP.HRS * DRATE
LET SE.RQMT(1) = SE.RQMT(2)     LET SE.RQMT(3) = 1
LET SE.O = SE.RQMT(1) * SE.COST(1) * 1.75
LET SE.I = SE.RQMT(2) * SE.COST(2) * 1.75
LET SE.D = SE.RQMT(3) * SE.COST(3) * 1.75
LET DIF.COST = TOT.COST
```

```
     IF WARR = 1
       LET TOT.COST = (WARR.COST + ECOST + PSPARES +CSPARES +
       LPSPARES + LCSPARES + OCOST + DCOST + ICOST + SE.I +
       SE.O + SE.D + TRANS)
     JUMP AHEAD   ELSE
     LET TOT.COST =
  (ECOST + FSPARES + CSPARES + LPSPARES + LCSPARES + OCOST + DCOST +
    ICOST + SE.I + SE.O + SE.D + TRANS)
     HERE   LET INT.COST = TOT.COST - DIF.COST
     LET INF.COST = INT.COST*((1 + (INFLAT/12))**(IMO))
     LET DIF.COST = TIN.COST
     LET TIN.COST = TIN.COST + INF.COST
     LET INT.COST = TIN.COST - DIF.COST
     LET DIS.COST= INT.COST*(1/((1+(DISC/12))**IMO))
     LET FIN.COST = FIN.COST + DIS.COST
     IF IMO=24
       LET RESULT(1,SIM)=FIN.COST
     JUMP AHEAD  ELSE
     IF IMO=96
       LET RESULT(2,SIM)=FIN.COST
     JUMP AHEAD  ELSE
     IF IMO = 168
       LET RESULT(3,SIM)=FIN.COST
     JUMP AHEAD  ELSE
     IF IMO=240
       LET RESULT(4,SIM)=FIN.COST
     ALWAYS  HERE
      IF IMO = MO.QUIT RETURN ELSE
     PERFORM INITIALIZATION
     RETURN   END
```

```
      EVENT REPORT
      ADD YR.REPORT/365 TO YR.START
      IF YR.REPORT > 365
      WRITE PRGM,YR.START - 1 + 1900 AS B 16,A 6,"STATUS REPORT-CY ",D(7,2)
      JUMP AHEAD  ELSE
      WRITE PRGM,YR.START+ 1900 AS B 16,A 6,"STATUS REPORT-CY ",D(7,2)
      HERE
      SKIP 1 LINE      WRITE FIN.COST AS B 17,"DISCOUNTED COST =$",D(13,2),/
      SCHEDULE A REPORT IN YR.REPORT DAYS
      RETURN   END
$       SOURCE
$       EXECUTE
$       LIMITS  15,40K,-3K,2000
$       FILE    B*,B1R
$       PRMFL   SL,R,S,CACI/SIM2LIB
$       PRMFL   17,R,S,CACI/SIMERR
$       DATA    05
$       SELECTA TEST100
$       SELECTA TEST.DAT
$       ENDJOB
```

APPENDIX B

PROGRAM LISTING FOR SHORT.3

The simulation model contained in this appendix is written in Simscript II.5 and is designed for use on the AFLC Honeywell system. The program is stored in the Create Time Sharing System under the name of SHORT.3 and uses data files stored under the names SHORT and TEST.DAT.

```
10##S,J :,8,16
20$      IDENT   WP0354,AFIT-LS  HELLESTO    WARR.3
30$      LIMITS  15,40K,,10K
40$      LOWLOAD
50$      OPTION  FORTRAN,NOMAP
60$      LIBRARY SL
70$      PROGRAM RLHS
80$      LIMITS  15,40K,,10K
90$      PRMFL   H*,R,R,CACI/SIM2.5
100$      FILE    *1
110$      FILE    *2
120$      FILE    B*,91S
130     PREAMBLE
140     NORMALLY MODE IS INTEGER
150     EVENT NOTICES INCLUDE
160       DEPLOYMENT,
170       ENGINE.REPAIR,
180       INSPECTION,
190       TCTO,
200       SCHED.TCTO,
210       END.OF.MO.STATS,
220       REPORT
230       EVERY INTER.REPAIR HAS AN PART
240       EVERY DEPOT.REPAIR HAS AN ITEM
250     DEFINE SPARE.CHECK AS A ROUTINE WITH 1 VALUE
260     DEFINE ICOUNT,EPCNT,LRUCNT,SCNT1,SCNT2,MAX,LCNT,SCNT
270       AS VARIABLES
280     DEFINE YR.START,YR.REPORT,YR.TCTO,MO.QUIT,YR.BEG AS REAL VARIABLES
290     DEFINE ECNT,FHT,IMO.FHP,INFREQ AS VARIABLES
300     DEFINE LRATE.OPG.HRS.INT.HRS,DEP.HRS.ENG.COST,EDH.HRS.TOT.COST.FIX.COST.
310      RFAC,MIL,CRATE,IRATE,DRATE,INFLAT,FIN.COST,DISC AS REAL VARIABLES
320     DEFINE SIRATE,SDRATE,SI.TOT,SI.PER,SD.TOT AS REAL VARIABLES
330     DEFINE PLANES,ENGS,B,TRANS,ETCOST.STCOST,LTCOST AS VARIABLES
340     DEFINE OCOST,ICOST,ICOST,ECOST,PSPARES.ISPARES AS VARIABLES
350     DEFINE LPSPARES,LCSPARES,SE.O,SE.I,SE.D AS VARIABLES
360     DEFINE TE,TL,TS.EDTIME.EBTIME,SDTIME,SBTIME.LDTIME AS VARIABLES
370     DEFINE SUR,ER,PROB,IMAX.IVER.PER AS REAL VARIABLES
380     DEFINE PQ, EREM,LRUREM,SRUREM AS A 1-DIMENSIONAL ARRAY
390     DEFINE EALL,EDEP,SPEC,ETCTO.LRUS.SRUS,DHRS,EBUY AS 1-DIMENSIONAL ARRAYS
400     DEFINE XEALL,XEDEP,XSPEC,XETCTO,XLRU,XSRU,XDHRS.XEBUY AS VARIABLES
410     DEFINE IS.HRS.DS.HRS,OL.HRS,IL.HRS,DL.HRS,PDAYS AS REAL VARIABLES
420     DEFINE LRUPROB,SRUPROB.CON.FAC AS 1-DIMENSIONAL REAL ARRAYS
430     DEFINE SCOST,LCOST,SE.COST,EFAIL AS 1-DIMENSIONAL REAL ARRAYS
440     DEFINE LRU.HRS, SRU.HRS AS 2-DIMENSIONAL REAL ARRAYS
450     DEFINE CONDEMS,LEVEL,SPARES,BASEQTY,SE.RQMT AS 1-DIMENSIONAL ARRAYS
460     DEFINE PRGM AS A ALPHA VARIABLE
470      DEFINE SEED,SED AS INTEGER VARIABLES
480     END
```

```
MAIN
RESERVE LRUPROB,SRUPROB AS 30
RESERVE LRUREM,SRUREM,SCOST,LCOST AS 30
RESERVE PD AS 132    RESERVE EREM AS 6
RESERVE BASEQTY AS 30     RESERVE SE.RQMT,SE.COST,EFAIL AS 3
RESERVE LRU.HRS AS 3 BY 30
RESERVE SRU.HRS AS 4 BY 30
RESERVE EALL,EDEP,SPEC,ETOTO,LRUS,SRUS,OHRS,EBUY AS 250
RESERVE LEVEL,SPARES,CON.FAC,CONDEMS AS 50
DEFINE NAME AS A 1-DIMENSIONAL ALPHA ARRAY  RESERVE NAME AS 2
DEFINE DATE AS A 1-DIMENSIONAL ALPHA ARRAY     RESERVE DATE AS 2
''------------------------------------------------------
READ DATE(1),DATE(2)      WRITE DATE(1),DATE(2) AS B 60,2 A 5,/
READ PRGM,ECNT,SVR,ENG.COST,RFAC,OVER.PER,WARR
LET SVR = SVR * RFAC
READ SE.COST(1),SE.COST(2),SE.COST(3),WARR.COST
READ FHR,INFREQ,IMAN,ORATE,IRATE,DRATE,EOH.HRS
LET ER.PROS = SVR * ECNT * INFREQ / 1000
READ TE,TL,TS,EDTIME,EBTIME,SDTIME,SBTIME,LDTIME
READ ETCOST,STCOST,LTCOST,INFLAT,DISC
READ YR.START,YR.REPORT,YR.TOTO,MO.QUIT,SEED,SED
LET YR.BEG = YR.START
READ EFAIL(1),EFAIL(2),EFAIL(3)
```

```
730     PRINT 37 LINES WITH PRGM.ECNT.ENG.COST,WARR.COST.SVR.EFAIL(1),EFAIL(2),
740       EFAIL(3),INFREQ,IMAN,FHP,EOH.HRS,SE.COST(1),OPATE.SE.COST(2),
750       IRATE,SE.COST(3),DRATE,TE,TS,TL,INFLAT.DISC,ETCOST,STCOST,LTCOST,
760       EDTIME,EBTIME,SDTIME,SBTIME,LDTIME,OVER.PER THUS
770             TURBINE ENGINE WARRANTY CONCEPT EVALUATION MODEL
780             3 LEVEL RUN FOR THE ****** PROGRAM
790
800 THE FOLLOWING PARAMETERS WERE USED IN THE EVALUATION:
810     A.  THE AIRCRAFT HAS ** ENGINES AT $ *********.** PER COPY
820         WARRANTY COST = $ *********.**
830     B.  SHOP VISIT RATE IS SET AT *.**/1000 HOURS
840     C.  FAILURE MODE DISTRIBUTION:
850          -MAJOR DAMAGE = .**%
860          -SRU CAUSED   = .**%
870          -LRU CAUSED   = .**%
880     D.  INSPECTION PARAMETERS:
890          -FREQUENCY = *** ENGINE OPERATING HOURS
900          -MANHOURS  = *** REQUIRED TO COMPLETE
910     E.  FLYING HOUR PROGRAM = ** HOURS / MONTH
920     F.  DEPOT HOURS FOR MAJOR DAMAGE = ***
930     G.                      S.E. COST PER SET        LABOR & MATERIAL HOURLY RATE
940         ORGANIZATIONAL      $ ********.**                              **
950         INTERMEDIATE        $ ********.**                              **
960         DEPOT               $ ********.**                              **
970     H.  TRANSPORTATION TIME (IN DAYS)
980          -ENGINE = *
990          -SRU    = *
1000          -LRU    = *
1010     I.  INFLATION RATE (PROJECTED AVERAGE) = *.**
1020         DISCOUNT RATE  =  *.**
1030     J.  TRANSPORTATION COSTS:
1040          -ENGINE = ***
1050          -SRU    = ***
1060          -LRU    = ***
1070     K.  IN WORK TIMES:
1080          -ENGINE (DEPOT) = **
1090          -ENGINE (BASE)  = **
1100          -SRU (DEPOT)    = **
1110          -SRU (BASE)     = **
1120          -LRU (DEPOT)    = **
1130     L.  PERCENTAGE OF AIRCRAFT DEPLOYED OVERSEAS  *.**%
1140     ""- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
```

```
     READ MAX  FOR I = 1 TO MAX READ PQ (I)
     SKIP 3 LINES   PRINT 2 LINES WITH PRGM THUS
              *****   DELIVERY SCHEDULE
 YR   J   F   M   A   M   J   J   A   S   O   N   D
     LET CY = YR.START    LET J = 1
     FOR K = 1 TO ((MAX + 11) / 12) DO
     WRITE CY AS I 4  LET JJ = J + 11
     FOR I = J TO JJ ADD PQ (I) TO TOT
     FOR I = J TO JJ WRITE PQ (I) AS (12) I 4
     WRITE TOT AS B 52, I 4,/  ADD TOT TO TOTAL  LET TOT = 0
     LET CY = CY + 1  LET J = J + 12
    LOOP
     WRITE TOTAL AS B 46,"TOTAL=",I 4,/
     ''- - - - - - - - - - - - - - - - - - - - - - - - -
     READ NO.OF.BASES   FOR I = 1 TO NO.OF.BASES READ BASEQTY (I)
     READ CIRP
     SKIP 1 LINE   PRINT 2 LINES THUS
 BASE DEPLOYMENT PRIORITY SCHEDULE
BASE #    # OF A/C
     FOR I = 1 TO NO.OF.BASES - 1 WRITE I,BASEQTY(I) AS I 5,I 10,/
     FOR I = 2 TO NO.OF.BASES LET BASEQTY(I) = BASEQTY(I) + BASEQTY(I-1)
     LET B = 1   LET SE.RQMT (2) = 1
     ''- - - SCHEDULE INSPECTIONS AND DEPLOYMENTS - - - - - - - - - -
     FOR I = 1 TO MAX  DO
     IF PQ (I) = 0 JUMP AHEAD  ELSE
     LET PDAYS = 30.42 / PQ (I)
     FOR J = 1 TO PQ(I) SCHEDULE AN INSPECTION IN
       (PDAYS * J) + (30.42 * (I - 1)) + ((INFREQ / FHP) * 30.42) DAYS
     FOR J = 1 TO PQ (I)
      SCHEDULE A DEPLOYMENT IN (PDAYS * J) + 30.42 * (I -1) DAYS
    HERE  LOOP
     '' SRU DATA - - - - - - - - - - - - - - - - - - - - - -
     START NEW PAGE    PRINT 4 LINES THUS
                    SRU RELIABILITY AND MAINTAINABILITY DATA
                  REPAIRED AT INTER         REPAIRED AT DEPOT
                  MAIN    INT    DEP        MAIN   INT    DEP    COST   COND
                  ACT     MHR    MHR        ACT    MHR    MHR   (000)   FAC.
     READ SCNT     FOR I = 1 TO SCNT  DO
     READ NAME(1),NAME(2),SIRATE,SRU.HRS(1,I),SRU.HRS(2,I),
       SDRATE,SRU.HRS(3,I),SRU.HRS(4,I),SCOST(I),CON.FAC(I)
     WRITE I,NAME(1),NAME(2),SIRATE,SRU.HRS(1,I),SRU.HRS(2,I),
       SDRATE,SRU.HRS(3,I),SRU.HRS(4,I),SCOST(I)/1000.,CON.FAC(I)
       AS I 2,B 4,2 A 6,3 D(7,1),S 4,3 D(7,1),D(6,0),D(7,2),/
     LET SRUPROB(I) = RFAC * (SIRATE + SDRATE) / (EFAIL(2) * SVR * 1000)
     LET SI.TOT = SI.TOT + SIRATE     LET SD.TOT = SD.TOT + SDRATE
   LOOP
```

```
    LET SI.PER = SI.TOT / (SI.TOT + SD.TOT)
    '' LRU DATA - - - - - - - - - - - - - - - - - - - - - - - -
    START NEW PAGE    PRINT 2 LINES THUS
            LRU RELIABILITY AND MAINTAINABILITY DATA                COND.
            REMOVAL RATE  ORG-MHRS  INTER-MHRS   DEP-MHRS  COST    FAC
    READ LCNT   FOR I = 1 TO LCNT  DO
    READ NAME(1),NAME(2),LRATE,LRU.HRS(1,I),LRU.HRS(2,I),LRU.HRS(3,I),
      LCOST(I),CON.FAC(I+SCNT)
    LET LRUPROB (I) = (LRATE * ECNT * INFREQ) / 1000000
    WRITE I,NAME(1),NAME(2),LRATE,LRU.HRS(1,I),LRU.HRS(2,I),LRU.HRS(3,I),
      LCOST(I),CON.FAC(I+SCNT)
      AS I 2,B 4,2 A 6,4 D(11,2),D(7,0),D(6,2),/
  LOOP
    SCHEDULE A REPORT IN  YR.REPORT  DAYS
    SCHEDULE A END.OF.MO.STATS IN 30.41 DAYS
    SCHEDULE A SCHED.TCTO IN 366 * YR.TCTO DAYS
    CALL ORIGIN.R(1,1,YR.START)
     START SIMULATION
     END
```

```
    EVENT DEPLOYMENT
    ADD 1 TO PLANES   ADD ECNT TO ENGS
    IF PLANES > BASEQTY (3) ADD 1 TO SE.RQMT (2) ADD 1 TO B
    ALWAYS  RETURN  END
```

```
    EVENT INSPECTION
    DEFINE SFAC AS A REAL VARIABLE    LET SFAC = 1.0
    ADD 1 TO ICOUNT   ADD ECNT * INFREQ TO FHT
    ADD IMAN TO ORG.HRS
    LET TO = 0   IF RANDOM.F(SED) < OVER.PER  LET TO = 10  ALWAYS
    '' CHECK FOR AN ENGINE REMOVAL
    IF RANDOM.F(SED) < ER.PROB GO TO 'REMOVE.ENG' ELSE GO TO 'CHECK.LRU'
'REMOVE.ENG'
    ADD 1 TO ERCNT    ADD 55 TO ORG.HRS
    DEFINE X AS A REAL VARIABLE  LET X = RANDOM.F(SEED)
    IF X < EFAIL(1) GO TO 'MAJOR.DAMAGE'  ELSE
    IF X > EFAIL(1) AND X < (1 - EFAIL(3)) GO TO 'SRU.CAUSED'
      ELSE GO TO 'LRU.CAUSED'
'MAJOR.DAMAGE'
    ADD 1 TO EREM(1)     ADD EOH.HRS TO DEP.HRS
    ADD ETCOST TO TRANS   ADD 10 TO ORG.HRS  '' PACK ENGINE
    SCHEDULE AN ENGINE.REPAIR IN TO + TE + EDTIME + TE DAYS
    PERFORM SPARE.CHECK(50)     GO TO 'CHECK.LRU'
'LRU.CAUSED'
    ADD 1 TO EREM(2)   ADD 46 TO INT.HRS
    SCHEDULE AN ENGINE.REPAIR IN 15 DAYS
   .PERFORM SPARE.CHECK(50)    GO TO 'CHECK.LRU'
'SRU.CAUSED'
    ADD 1 TO EREM(3)
    SCHEDULE AN ENGINE.REPAIR IN EBTIME DAYS
    PERFORM SPARE.CHECK(50)
    IF RANDOM.F(SEED) > SI.PER GO TO 'DEPOT.REPAIR.OF.SRU'  ELSE
'IREPAIR.OF.SRU'
    ADD 1 TO EREM(4)       ADD LTCOST TO TRANS '' COMPONENT
    FOR I = 1 TO SCNT   DO
     IF RANDOM.F(SEED) < SRUPROB(I)
       ADD 1 TO SRUREM(I)    ADD 1 TO SCNT1
       ADD SRU.HRS(1,I) * SFAC TO INT.HRS
       ADD SRU.HRS(1,I)*SFAC TO IS.HRS
       LET SFAC = .6
       ADD SRU.HRS(2,I) TO DEP.HRS
       ADD SRU.HRS(2,I) TO DS.HRS
       SCHEDULE A INTER.REPAIR(I) IN SBTIME DAYS
       PERFORM SPARE.CHECK(I)
    ALWAYS  LOOP     GO TO 'CHECK.LRU'
'DEPOT.REPAIR.OF.SRU'
    ADD 1 TO EREM(5)    ADD STCOST TO TRANS
```

```
    FOR I = 1 TO SCNT   DO
     IF RANDOM.F(SED) < SRUPROB(I)
       ADD 1 TO SRUREM (I)    ADD 1 TO SCNT2
       ADD SRU.HRS(3,I) * SFAC TO INT.HRS
       ADD SRU.HRS(3,I)*SFAC TO IS.HRS
       LET SFAC = .6
       ADD SRU.HRS(4,I) TO DEP.HRS
       ADD SRU.HRS(4,I) TO DS.HRS
       SCHEDULE A DEPOT.REPAIR(I) IN TO + TS + TO + SDTIME + TS DAYS
      PERFORM SPARE.CHECK(I)
    ALWAYS   LOOP
'CHECK.LRU
     '' CHECK FOR AN LRU FAILURE
    FOR I = 1 TO LCNT   DO
      IF RANDOM.F(SEED) < LRUPROB (I) ADD 1 TO LRUCNT
       ADD 1 TO LRUREM (I)      ADD LTCOST TO TRANS
       ADD LRU.HRS(1,I) TO ORG.HRS
       ADD LRU.HRS(1,I) TO OL.HRS
       ADD LRU.HRS(2.I) TO INT.HRS
       ADD LRU.HRS(2.I) TO IL.HRS
       ADD LRU.HRS(3,I) TO DEP.HRS
       ADD LRU.HRS(3,I) TO DL.HRS
       LET II = I + SCNT
       SCHEDULE A DEPOT.REPAIR (II) IN TO + TL + LDTIME + TL DAYS
      PERFORM SPARE.CHECK(II)
      ALWAYS
    LOOP
  HERE
    SCHEDULE AN INSPECTION IN (INFREQ / FHP) * 30.42 DAYS
    RETURN END
```

```
     EVENT INTER.REPAIR(PART)
     IF RANDOM.F(SEED) > CON.FAC(PART) ADD 1 TO LEVEL(PART)  JUMP AHEAD
       ELSE  ADD 1 TO CONDEMS (PART)
    HERE  RETURN END

     EVENT DEPOT.REPAIR(ITEM)
     IF RANDOM.F(SED) > CON.FAC(ITEM) ADD 1 TO LEVEL(ITEM)  JUMP AHEAD
       ELSE  ADD 1 TO CONDEMS (ITEM)
    HERE  RETURN END

     EVENT ENGINE.REPAIR
     ADD 1 TO LEVEL(50)
     RETURN  END

     SUBROUTINE SPARE.CHECK(NUM)
     SUBTRACT 1 FROM LEVEL(NUM)
     IF NUM = 50 GO TO 'ENG.LOGIC'  ELSE
     IF NUM > SCNT GO TO 'LRU.LOGIC'  ELSE
'SRU.LOGIC'
     IF LEVEL(NUM) < 0  ADD 1 TO SPARES(NUM)  ADD 1 TO LEVEL (NUM)
      ALWAYS  JUMP AHEAD
'ENG.LOGIC'
     IF LEVEL(50) < B / 2 ADD 1 TO SPARES(NUM)  ADD 1 TO LEVEL(NUM)
       ALWAYS  JUMP AHEAD
'LRU.LOGIC'
     IF LEVEL(NUM) < B / 2 ADD 1 TO SPARES(NUM)  ADD 1 TO LEVEL(NUM)
       ALWAYS  HERE  RETURN  END

     EVENT TCTO
     ADD 1 TO EREM(6)
     SCHEDULE AN ENGINE.REPAIR IN 7 DAYS
       PERFORM SPARE.CHECK(50)
     RETURN  END

     EVENT SCHED.TCTO
     LET TCNUM = ENGS - (12*EALL(IMO))
     FOR I = 1 TO TCNUM  SCHEDULE A TCTO IN (360 / TCNUM) * I DAYS
     SCHEDULE A SCHED.TCTO IN 365 * YR.TCTO DAYS
     RETURN  END
```

```
EVENT END.OF.MO.STATS
ADD 1 TO IMO
IF IMO = 1
  LET EALL(1) = ERCNT     LET EDEP(1) = EREM(1)
  LET SPEC(1) = ICOUNT    LET ETCTO(1) = EREM(6)
  LET LRUS(1) = LRUCNT    LET SRUS(1) = SCNT1 + SCNT2
  LET DHRS(1) = DEP.HRS   LET EBUY(1) = SPARES(50)
 JUMP AHEAD   ELSE
LET EALL(IMO) = ERCNT - XEALL
LET EDEP(IMO) = EREM(1) - XEDEP
LET SPEC(IMO) = ICOUNT - XSPEC
LET ETCTO(IMO) = EREM(6) - XETCTO
LET LRUS(IMO) = LRUCNT - XLRU
LET SRUS(IMO) = SCNT1 + SCNT2 - XSRU
LET DHRS(IMO) = DEP.HRS - XDHRS
LET EBUY(IMO) = SPARES(50) - XEBUY
HERE  SCHEDULE A END.OF.MO.STATS IN 30.42 DAYS
LET XEALL = ERCNT     LET XEDEP = EREM(1)
LET XSPEC = ICOUNT    LET XETCTO = EREM(6)
LET XLRU = LRUCNT     LET XSRU = SCNT1 + SCNT2
LET XDHRS = DEP.HRS    LET XEBUY = SPARES(50)
LET ECOST = SPARES(50) * ENG.COST
FOR I = 1 TO SCNT
  LET PS = PS + ((SPARES(I) - CONDEMS(I)) * SCOST(I))
  LET PSPARES = PS
  LET PS = 0
FOR I = 1 TO SCNT
  LET CS = CS + (CONDEMS(I) * SCOST(I))
  LET CSPARES = CS
  LET CS = 0
FOR I = 1 + SCNT TO SCNT + LCNT
  LET LPS = LPS + ((SPARES(I) - CONDEMS(I)) * LCOST(I - SCNT))
  LET LPSPARES = LPS
  LET LPS = 0
FOR I = 1 + SCNT TO SCNT + LCNT
  LET LCS = LCS + (CONDEMS(I) * LCOST(I - SCNT))
  LET LCSPARES = LCS
  LET LCS = 0
LET OCOST = ORG.HRS * ORATE
LET ICOST = INT.HRS * IRATE
LET DCOST = DEP.HRS * DRATE
LET SE.RQMT(1) = SE.RQMT(2)     LET SE.RQMT(3) = 1
LET SE.O = SE.RQMT(1) * SE.COST(1) * 1.75
LET SE.I = SE.RQMT(2) * SE.COST(2) * 1.75
LET SE.D = SE.RQMT(3) * SE.COST(3) * 1.75
LET DIF.COST = TOT.COST
```

```
    IF WARR = 1
      LET TOT.COST = (WAR.COST + ECOST + PSPARES +CSPARES +
      LPSPARES + LCSPARES + OCOST + DCOST + ICOST + SE.I +
      SE.O + SE.D + TRANS)
    JUMP AHEAD   ELSE
    LET TOT.COST =
 (ECOST + PSPARES + CSPARES + LPSPARES + LCSPARES + OCOST + DCOST +
   ICOST + SE.I + SE.O + SE.D + TRANS)
  . HERE   LET INT.COST = TOT.COST - DIF.COST
    LET INF.COST = INT.COST*((1 + (INFLAT/12))**(IMO))
    LET DIF.COST = TIN.COST
    LET TIN.COST = TIN.COST + INF.COST
    LET INT.COST = TIN.COST - DIF.COST
    LET DIS.COST= INT.COST*(1/((1+(DISC/12))**IMO))
    LET FIN.COST = FIN.COST + DIS.COST
     IF IMO < MO.QUIT RETURN ELSE
    START NEW PAGE     PRINT 1 LINE WITH FROM THUS
             **** PROJECTED MAINTENANCE WORKLOAD
    FOR I = 1 TO IMO WRITE YR.BEG + 1900 + (I/12) AS D(10,2)
    SKIP 1 LINE  PRINT 1 LINE THUS
INSPECTIONS
    FOR I = 1 TO IMO WRITE SPEC(I) AS I 10
    SKIP 1 LINE  PRINT 1 LINE THUS
ENGINE REMOVALS (EXCLUDING TCTOS)
    FOR I = 1 TO IMO WRITE EALL(I) AS I 10
    SKIP 1 LINE  PRINT 1 LINE THUS
ENGINE REMOVALS (DEPOT)
    FOR I = 1 TO IMO WRITE EDEP(I) AS I 10
    SKIP 1 LINE  PRINT 1 LINE THUS
ENGINE REMOVALS (TCTO)
    FOR I = 1 TO IMO  WRITE ETCTO(I) AS I 10
    SKIP 1 LINE  PRINT 1 LINE THUS
SPARE ENGINE REQUIREMENTS
    FOR I = 1 TO IMO  WRITE EBUY(I) AS I 10
    SKIP 1 LINE  PRINT 1 LINE THUS
MAINTENANCE ACTIONS (SRUS)
    FOR I = 1 TO IMO WRITE SRUS(I) AS I 10
    SKIP 1 LINE  PRINT 1 LINE THUS
LRU REMOVALS
    FOR I = 1 TO IMO  WRITE LRUS(I) AS I 10
    SKIP 1 LINE  PRINT 1 LINE THUS
DEPOT MANHOURS
    FOR I = 1 TO IMO  WRITE DHRS(I) AS I 10
    STOP   END
```

```
    EVENT REPORT
    START NEW PAGE
    ADD YR.REPORT/365 TO YR.START
    IF YR.REPORT > 365
    WRITE PRGM,YR.START - 1 + 1900 AS B 16,A 6,"STATUS REPORT-CY ",D(7,2)
    JUMP AHEAD  ELSE
    WRITE PRGM,YR.START+ 1900 AS B 16,A 6,"STATUS REPORT-CY ",D(7,2)
    HERE  SKIP 2 LINES
    PRINT 3 LINES WITH FHT, FHT / ECNT,ICOUNT THUS
  ********.** ENGINE FLYING HOURS
  ********.** FLEET FLYING HOURS
                   *** INSPECTIONS PERFORMED
    SKIP 1 LINE   PRINT 4 LINE WITH LRUCNT,OL.HRS*ORATE,IL.HRS*IRATE,
    DL.HRS*DRATE,LCNT THUS
ON-WING MAINTENANCE ACTIVITY
  TO DATE *****  LRUS HAVE BEEN REMOVED, TOTAL MHRS & LABOR ARE
  O-LEVEL=$*********.**, I-LEVEL=$*********.** ,D-LEVEL=$*********.**
  DISTRIBUTED AMONG THE ** IDENTIFIED LRUS AS FOLLOW:
    FOR I = 1 TO LCNT  WRITE LRUREM (I) AS  I 5
     SKIP 1 LINE
    SKIP 1 LINE   PRINT 6 LINES WITH
     ERCNT,EREM(1),EREM(2).EREM(3).EREM(6) THUS
ENGINE REMOVAL INFORMATION
 *** ENGINES REMOVED (TOTAL EXCLUDING TCTOS)
    *** ENGINES REMOVED - MAJOR ENGINE DAMAGE
    *** ENGINES REMOVED - MINOR REPAIR - LRU
    *** ENGINES REMOVED - SRU CAUSED
 *** ENGINES REMOVED - TCTO
    SKIP 1 LINE
    PRINT 3 LINES WITH SCNT1 + SCNT2,SCNT1,IS.HRS*IRATE,SCNT2,
    DS.HRS*DRATE,SCNT THUS
  TO DATE ***** SRU MAINTENANCE ACTIONS HAVE TAKEN PLACE, DIVIDED AS
   (I-LEVEL=*****,$*********.**, D-LEVEL=*****,$*********.**) AND
    DISTRIBUTED AMONG THE ** IDENTIFIED SRUS AS FOLLOW:
    FOR I = 1 TO SCNT  WRITE SRUREM (I) AS  I 5
    SKIP 2 LINES      PRINT 1 LINE WITH SPARES(50),ECOST THUS
SPARE ENGINE REQUIREMENTS (FAILURES AND TCTOS)  ****   $*********.**
    SKIP 1 LINE    PRINT 1 LINE WITH PSPARES THUS
SPARE SRU REQMTS (PIPELINE) $*********.**   BROKEN DOWN AS FOLLOWS:
    FOR I = 1 TO SCNT WRITE SPARES(I) - CONDEMS(I) AS  I 4
    SKIP 1 LINE    PRINT 1 LINE WITH CSPARES THUS
SPARE SRU REQMTS (CONDEMS)  $*********.**   BROKEN DOWN AS FOLLOWS:
    FOR I = 1 TO SCNT  WRITE CONDEMS(I) AS I 4
    SKIP 1 LINE   PRINT 1 LINE WITH LPSPARES THUS
SPARE LRU REQMTS (PIPELINE) $*********.**   BROKEN DOWN AS FOLLOWS:
```

```
    FOR I = 1 + SCNT TO SCNT + LCNT WRITE SPARES (I) - CONDEMS(I) AS I 4
    SKIP 1 LINE   PRINT 1 LINE WITH LCSPARES THUS
SPARE LRU REQMTS (CONDEMS)  $*********.**   BROKEN DOWN AS FOLLOWS:
    FOR I = 1 + SCNT TO SCNT + LCNT WRITE CONDEMS (I) AS I 4
    SKIP 1 LINE PRINT 7 LINES WITH
     ORG.HRS,INT.HRS,DEP.HRS,
    OCOST,ICOST,DCOST,
     SE.RQMT(1),SE.RQMT(2),SE.RQMT(3),SE.O,SE.I,SE.D THUS
                       ORG-LEVEL        INTER-LEVEL       DEPOT LEVEL
MAINTENANCE
 MANHOURS                 ***                 ****               ***
 DOLLARS          $*********.**      $*********.**      $*********.**
SUPPORT EQUIPMENT
 UNITS                    ***                 ****               ***
 DOLLARS          $*********.**      $*********.**      $*********.**
    SKIP 1 LINE  PRINT 1 LINE WITH TRANS THUS
TRANSPORTATION REQUIREMENTS=$*********.**
    SKIP 1 LINE    WRITE TOT.COST AS B 17,"TOTAL COST=$",D(13,2),/
     SKIP 1 LINE     WRITE TIN.COST AS B 17,"INFLATED COST =$",D(13,2),/
    SKIP 1 LINE      WRITE FIN.COST AS B 17,"DISCOUNTED COST =$",D(13,2),/
    SKIP 1 LINE   WRITE FIN.COST/FHT AS B 17,"COST/EFH = $",D(13,2),/
    SKIP 1 LINE   PRINT 1 LINE THUS
 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
    SCHEDULE A REPORT IN YR.REPORT DAYS
    RETURN   END
$      SOURCE
$      EXECUTE
$      LIMITS  11,20K,-3K,2000
$      FILE    B*,E1F
$      PRMFL   SL,R,S,CACI SIM2LIB
$      PRMFL   17,R,S,CACI/SIMERR
$      DATA    05
$      SELECTA SHORT
$      SELECTA TEST.DAT
$      ENDJOB
```

APPENDIX C

INPUT DATA ELEMENT DICTIONARY

Introduction: The Data Element Dictionary defines all input parameters into both versions of the simulation model. They are presented in alphabetical order with respect to the variable name.

CON.FAC(I)	Real	The percentage of the total of all failures that are not reparable and must be replaced.
DATE(I)	Alpha	The date of the last revision of the data set.
DISC	Real	The discount rate at which the costs are converted back to a single year dollar set.
DRATE	Real	The rate used for cost accounting of depot work. It includes both labor and materials.
EBTIME	Integer	The total time necessary for repair of an engine on base including repair and testing.
ECNT	Integer	The total number of engines per aircraft.
EDTIME	Integer	The total time an engine is out of service due to depot repair.
EFAIL(A)	Real	Distribution of failures expressed as a percentage for SRU, LRU or Major Engine Failure.
ENG.COST	Real	Total cost of a spare engine.
EOH.HRS	Real	Total hours required for a total engine overhaul.
ETCOST	Integer	Cost to transport an engine from base to depot.
FHP	Integer	Total flying hours per month that each A/C will accrue.
IMAN	Real	Organizational manhours required for the inspection of an engine.
INFLAT	Real	The expected rate of inflation.
INFREQ	Integer	Interval in aircraft flying hours between inspections.

IRATE	Real	The rate used for cost accounting of intermediate work and includes labor and materials.
LCNT	Integer	The total number of LRUs identified in the engine.
LCOST(I)	Real	Cost of each individual LRU.
LDTIME	Integer	The total time necessary for repair of an LRU at depot level. Including repair and testing but not transportation.
LRATE	Real	The projected removal rate for each LRU.
LRU.HRS(A,I)	Real	Manhours required for the repair process for each LRU when A is the level and I is the item.
LTCOST	Integer	Transportation cost for shipping an LRU from base to depot.
MAX	Integer	Total number of aircraft in the simulation.
MO.QUIT	Real	The total number of months to be simulated.
NAME(A)	Alpha	Two part names for each SRU and LRU.
NO.OF.BASES	Integer	Total number of bases to be activated.
ORATE	Real	The rate used for cost accounting of organizational level work. It includes both labor and materials.
OVER.PER	Real	The percentage of aircraft to be deployed overseas.
PQ(I)	Integer	The number of aircraft to be delivered each month.
PRGM	Alpha	Title of the modeled system.

RFAC	Real	Conversion factor for analysis of probability distributions on SRU and LRU failures.
SBTIME	Integer	Time necessary for repair of an SRU at base level.
SCNT	Integer	Total number of SRUs identified in the engine.
SCOST(I)	Real	The cost of each SRU.
SDRATE	Real	The projected removal rate for SRUs to be repaired at depot level.
SDTIME	Integer	Time necessary for repair of an SRU at the depot.
SECOST(A)	Real	Support Equipment kit costs at the three levels.
SED	Integer	Random number generator seed selector.
SEED	Integer	Random number generator seed selector.
SIRATE	Real	The projected removal rate for SRUs to be repaired at the I level.
SRU.HRS(A,I)	Real	Total hours for repair of an SRU at either intermediate or depot.
STCOST	Integer	Cost to transport an SRU from base to depot.
SVR	Real	The projected rate at which engines are removed and sent to the intermediate shop.
TE	Integer	Transportation time in days from base to depot for an engine.
TL	Integer	Transportation time in days from base to depot for an LRU.

TS	Integer	Transportation time in days from base to depot for an SRU.
WARR	Integer	Indicator as to warranty or non-warranty option.
WARR.COST	Real	Total cost of the warranty package.
YR.REPORT	Real	Period between reports.
YR.START	Real	Year in which the simulation starts.
YR.TCTO	Real	Time interval between scheduled TCTOs.

APPENDIX D

INTERNAL VARIABLE DICTIONARY

Introduction: The Internal Variable Dictionary provides a definition for the internal variables of the two versions of the simulation model. These definitions are useful in understanding the logic of the simulation strategy.

B	Integer	Indicator of bases.
CONDEMS(ITEM)	Integer	Total parts condemned at depot level for each SRU and LRU.
CONDEMS(PART)	Integer	Total parts condemned at intermediate level for each SRU and LRU.
CS	Integer	Intermediate variable for calculating CSPARES.
CSPARES	Integer	Total spares of each SRU procured to replace condemned SRUs.
CY	Integer	Incremented variable based on YR.START for output with delivery schedule.
DCOST	Integer	Total cost for labor and material at the depot level.
DEP.HRS	Real	Total depot hours expended to date.
DHRS(IMO)	Integer	Monthly depot hours incurred.
DIF.COST	Real	Intermediate variable for accounting of total costs and total inflated costs to date of the previous month.
DIS.COST	Real	Total discounted costs of the current month.
DL.HRS	Real	Total D-level hours accrued associated with SRU repair.
DS.HRS	Real	Total depot hours accrued associated with SRU repair.
EALL(IMO)	Integer	Monthly engine removal count.
EBUY(IMO)	Integer	Monthly spare engine procurements.
ECOST	Integer	Total cost of all spare engines procured.

EDEP(IMO)	Integer	Monthly major engine removals.
ENGS	Integer	Tabulator for total engines in the system.
ERCNT	Integer	Counter for total engine removals to date.
EREM(1)	Integer	Major engine damage counter.
EREM(2)	Integer	Total LRU caused engine removals to date.
EREM(3)	Integer	Total SRU caused engine removals to date.
EREM(4)	Integer	Total engine removals due to SRU failure and repaired at I-level.
EREM(5)	Integer	Total engine removals due to SRU failure and repaired at D-level.
EREM(6)	Integer	Total engine removals due to TCTO actions.
ER.PROB	Real	Probability of an engine removal.
ETCTO(IMO)	Integer	Monthly TCTO driven removals.
FHT	Integer	Tabulator of total engine flying hours.
FIN.COST	Real	Total cost including inflation and discounting to date.
I	Integer	Counter.
ICOST	Integer	Total cost for labor and material at the intermediate level.
ICOUNT	Integer	Tabulator of total number of inspections having occurred.
II	Integer	Counter.
IL.HRS	Real	Total I-level hours accrued associated with LRU repair.

IMO	Integer	Month indicator.
INF.COST	Real	Total inflated costs of the current month.
INT.COST	Real	Total inflated cost to date of the previous month.
INT.HRS	Real	Total intermediate hours expended to date.
IS.HRS	Real	Total intermediate hours accrued associated with SRU repair.
J	Integer	Counter.
JJ	Integer	Counter.
K	Integer	Counter.
LCS	Integer	Intermediate variable used to calculate LCSPARES.
LCSPARES	Integer	Total spares of each LRU procured to replace condemned LRUs.
LEVEL(50)	Integer	Total spare engines available.
LEVEL(ITEM)	Integer	Total spare parts available for each SRU and LRU.
LEVEL(PART)	Integer	Level to date of each spares pool of LRUs and SRUs.
LPS	Integer	Intermediate variable for calculating LPSPARES.
LPSPARES	Integer	Total spares of each LRU procured to fill the pipeline.
LRUPROB(I)	Real	Probability for failure of a specified LRU.
LRUREM(I)	Integer	Total LRU removals by each type.
LRUS(IMO)	Integer	Monthly LRU removal count.

NUM	Integer	Incremented identifier for SRUs and LRUs.
OCOST	Integer	Total cost for labor and material at the organizational level.
OL.HRS	Real	Total O-level hours accrued associated with LRU repair.
ORG.HRS	Real	Tabulator for total number of organizational hours utilized.
PDAYS	Real	Time in between delivery of aircraft during a specified month.
PLANES	Integer	Tabulator for total aircraft in the system.
PS	Integer	Intermediate variable for calculating PSPARES.
PSPARES	Integer	Total spares of each SRU procured to fill the pipeline.
SCNT1	Integer	Total SRUs failed and repaired at I-level.
SCNT2	Integer	Total SRUs failed and repaired at D-level.
SD.TOT	Real	Total maintenance actions for SRUs at D-level.
SE.D	Integer	Total cost for SE at the depot level.
SED	Integer	Incremented argument for randomizing the number generator.
SEED	Integer	Incremented argument for randomizing the number generator.
SE.I	Integer	Total cost for SE at the intermediate level.

SE.O	Integer	Total cost for SE at the organizational level.
SE.RQMT(1)	Integer	Total SE sets required for the O-level.
SE.RQMT(2)	Integer	Total SE sets required for the I-level.
SE.RQMT(3)	Integer	Total SE sets required for the D-level.
SFAC	Real	Factor for reduction in labor hours due to multiple failures in one removal.
SI.PER	Real	Probability of depot repair of an SRU.
SI.TOT	Real	Total maintenance actions for SRUs at I-level.
SPARES(NUM)	Integer	Total spare engines procured.
SPEC(IMO)	Integer	Monthly inspections.
SRUPROB(I)	Real	Probability for failure of a specified SRU.
SRUREM(I)	Integer	Total removals of each SRU.
TCNUM	Integer	Accounts for engines having complied with TCTO actions and not requiring further scheduling.
TIN.COST	Real	Total inflated cost to date.
TO	Integer	Factor for addition of extra repair time if engine is overseas.
TOT	Integer	Total number of engines delivered in one year.
TOTAL	Integer	Total number of engines delivered.
TOT.COST	Real	Basic total cost to date.

TRANS	Integer	Total transportation costs incurred to date.
X	Integer	Random variable for determination of engine failure mode.
XDHRS	Integer	Total report hours incurred (to previous month).
XEALL	Integer	Total engine removals (to previous month).
XEBUY	Integer	Total spare engines procured (to previous month).
XEDEP	Integer	Total major engine removals (to previous month).
XETCTO	Integer	Total TCTO driven engine removals (to previous month).
XLRUS	Integer	Total LRU removals (to previous month).
XSPEC	Integer	Total inspections (to previous month).
XSRUS	Integer	Total SRU removals (to previous month).
YR.BEG	Real	A static variable allowing the incremented variable YR.START to be used at a later point.

APPENDIX E

MODEL LOGIC

The purpose of this appendix is to provide an indepth view of the model logic to provide an understanding of the actual process used to simulate the Engine O&S System. This analysis is accomplished by a reverse flow process. The analysis starts with the monthly statistics event and defines the derivation of the final cost. Each Discrete Event is then discussed.

Event Monthly Statistics

Final Discounted Cost

This is the measure of system performance and is the major piece of data collected. It is calculated from the total inflated O&S costs using the following formula:

$$\begin{matrix}\text{Discounted Cost} \\ \text{for Month IMO}\end{matrix} = \begin{matrix}\text{Inflated Cost} \\ \text{for Month IMO}\end{matrix} \left(\frac{1}{1+\left(\frac{\text{Discount Rate}}{12}\right)^{\text{IMO}}} \right)$$

The discounting is done on a monthly basis and is accomplished in order to provide a true representation of costs in similar year dollars. As stated before, the discounted costs are derived from inflated cost as shown in the following paragraph.

Inflated Cost

This cost is an adjusted O&S aggregate cost after inflation growth. The inflation calculation is performed as follows:

$$\begin{matrix}\text{Inflated Cost} \\ \text{for Month IMO}\end{matrix} = \begin{matrix}\text{Monthly Aggregate} \\ \text{O\&S Cost}\end{matrix} \left(1 + (\text{Inflation Rate}/12)^{\text{IMO}} \right)$$

Monthly Aggregate O&S Cost

This is the total of all monitored costs and involves the summation of a number of variable values. Each variable will be discussed and traced back to their respective origins.

The first variable, WARR.COST, is the cost of the warranty. Not only is this value an input to the aggregate cost, it is a direct input as a system parameter. Therefore, this value is supplied directly from input without any transformation.

Second is the total cost for spare engines (ECOST) which is computed by a multiplication of the total engines required for spare assets by the actual cost of the engines. The latter is an input value while the former is accumulated as follows. During the spare check routine, the level of engines is queried. If it is below a level equal to 1/2 the total number of bases, another engine is procured. Engines are decremented from the spares level at the beginning of the spare check routine as a result of engine removals in the inspection event. An engine removal can occur due to major damage, LRU failure or SRU failure. The decision factor is the input parameter "failure mode distribution" which defines the percentage of all removals attributed to each of the three possibilities. The use of a simple random number generator allows the use of these probabilities in randomizing the decision. The overall engine removal decision is controlled by another random number generator compared to an engine

removal probability. This probability is calculated from the product of three input parameters; shop visit rate, total number of engines on the aircraft, and the inspection frequency divided by 1000:

ER.PROB = (SVR*ECNT*INFREQ)/1000

Having derived the total engine cost, the third cost factor is the cost of pipeline SRU and LRU spares.

SRU/LRU Spares Cost (Pipeline)

The pipeline is defined as the total number of units necessary to allow normal operations taking into accound repair times, transportation times and failure rates. These costs for the total number of SRU or LRU spares necessary to fill the pipeline is calculated by the product of the total number required, times their individual costs. The individual unit costs are stored in an array and each month the total cost is calculated for each SRU or LRU. This total cost calculation is accomplished by taking the total units procured and subtracting the total number of units condemned. This gives a true figure of SRUs or LRUs required solely for the pipeline. Total SRU/LRU procurements are driven by the spare check subroutine which causes the purchase of a specified unit if the total in the spares pool falls to zero for SRUs, or less than 1/2 of the total number of bases for LRUs. Spares pool usage is, in turn, controlled by item removals in the inspection event. The probability of an SRU or LRU failure is generated using the following equations for SRUs and LRUs:

$$\text{SRU.PROB} = \left(\begin{array}{l}\text{Expected}\\\text{Mainte-}\\\text{nance}\\\text{Actions}\\\text{at Inter-}\\\text{mediate}\end{array} + \begin{array}{l}\text{Expected}\\\text{Mainte-}\\\text{nance}\\\text{Actions}\\\text{at Depot}\end{array} \right) \Bigg/ \left(\begin{array}{l}\text{SRU}\\\text{Failure}\\\text{Rate}\\\text{Proba-}\\\text{bility}\end{array} * \begin{array}{l}\text{Shop}\\\text{Visit}\\\text{Rate}\end{array} * 1000 \right)$$

$$\text{LRU.PROB} = \left(\begin{array}{l}\text{Maintenance}\\\text{Actions}\end{array} * \begin{array}{l}\text{Total \#}\\\text{of Engines}\end{array} * \begin{array}{l}\text{Inspection}\\\text{Frequency}\end{array} \right) \Big/ 1{,}000{,}000$$

All of the required data is provided as values to input parameters. The use of a random number generator output to compare to the probability on each SRU or LRU simulates the failure in a real life situation.

SRU/LRU Spares (Condemnation)

The total cost for condemned spare SRUs or LRUs is calculated in the same manner as the pipeline spares with the addition of one factor; that of condemnation. It can be seen in Figure E-1 that during the repair event the decision to condemn is accomplished using a random number which is compared to the appropriate input condemnation factor. The total number of condemned units is tallied and the costs are accumulated by the simple multiplication of the total condemned units times their procurement cost. The latter is an input value.

Organizational, Intermediate and Depot Costs

The next three factors in the aggregate cost include the manhour and material costs for the three maintenance levels. Organizational, Intermediate and Depot hours are accrued throughout the system. They are each accumulated in their

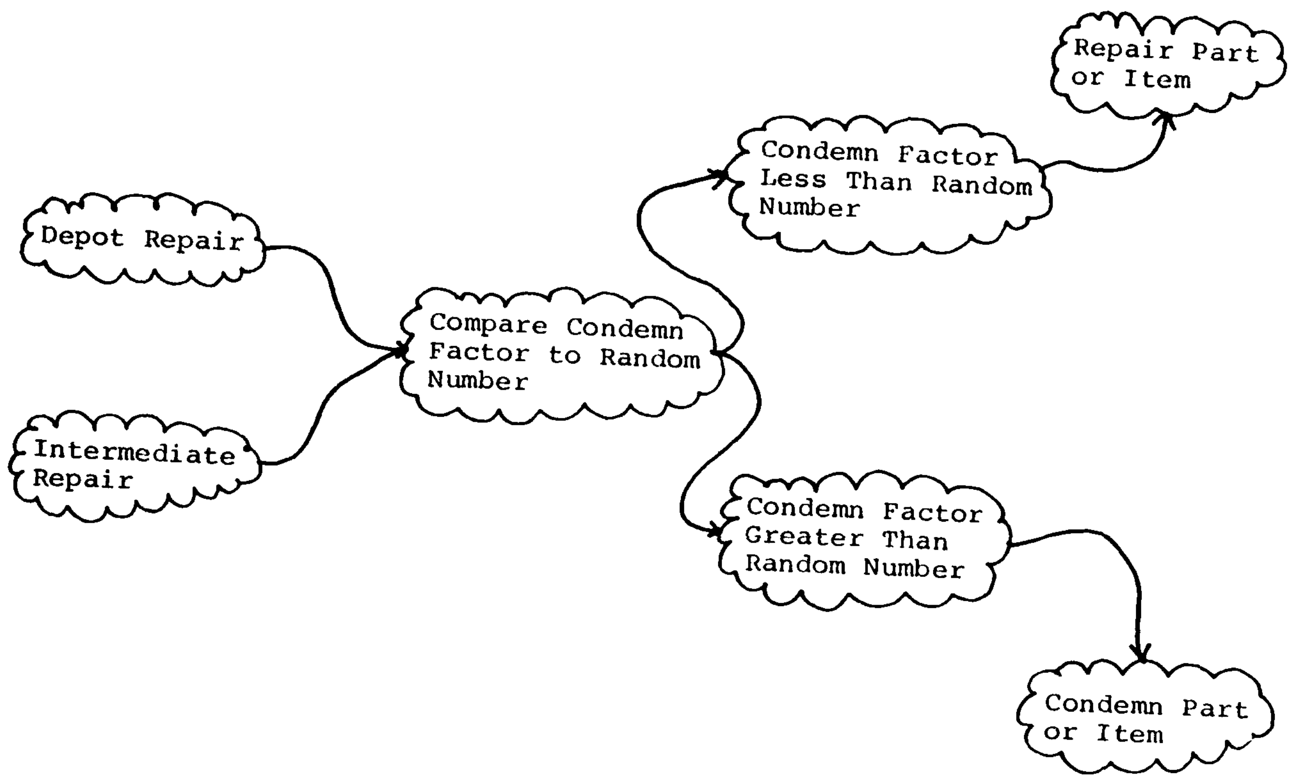


Figure E-1 Condemnation Process

respective counters and costs are calculated monthly by multiplying the total hours by the input manhour and material hourly costs. The accumulation process for the next three aggregate factors are roughly similar.

Support Equipment Costs - O-I-D Levels

The cost for support equipment sets is defined as the total number of sets required at each level times their individual procurement costs. The latter value is input to the system as a parameter value. Total S.E. kit requirements are determined in the deployment event where the system procures organizational and intermediate sets for each base and one depot set for the entire system. Therefore, the input total number of bases drives the support equipment set buy.

Transportation Costs

The last aggregate cost is for the cost of transporting the SRUs, LRUs and engines between base and depot. This cost is directly accumulated throughout the system when a unit of any type is transported. The cost for transporting each type is provided as a value for an input parameter.

To this point the accrual of total costs and, in some manner, how they tie back to the rest of the system has been discussed. However, it should be of interest to the reader how each of the specific events function. Therefore, we will now analyze each event at the micro level and explain the logic involved.

Event Deployment

In this event, the intent is to bring those aircraft into operational services which were scheduled for deployment in the main portion of the program. The total number of planes is increased as is the total number of engines. The total number of planes is compared to the total required for the current base and, if necessary, a new base is initialized with support equipment kits.

Event Inspection

Within this event the inspection, fault isolation, and repair scheduling functions are portrayed. We start with the bookkeeping functions such as incrementing the total number of inspections completed, the total number of flying hours and charging the inspection manhours to the organizational hour counter. A check is then made to determine if the aircraft is overseas. If the randomly generated number is less then the input variable overseas percentage (OVER.PER) then the time for transport overseas (TO) is set to 10 as opposed to 0 for the CONUS.

The next check is for an engine removal as a result of the inspection. As stated before, the engine removal probability is calculated as follows:

$$\left((\text{Shop Visit Rate}) * \begin{matrix}\text{\# of Engines}\\ \text{per A/C}\end{matrix} * \begin{matrix}\text{Inspection}\\ \text{Frequency}\end{matrix} \right) \Big/ 1000$$

If the random number drawn is smaller than the engine removal probability, the engine is removed and action is transferred

to the Check LRU subunit which will be discussed later.

Remove Engine

This is the decision point for cause of failure. Using the Failure Mode Distribution input values and a randomly generated number the failure type is determined. Action is then transferred to either Major Damage, SRU Caused, or LRU Caused after the engine removal count is increased by one.

Major Damage

In this section we simulate the activities which result after a catastrophic failure of an engine. First the bookkeeping where major damage failures are incremented by one, the input parameter Engine Overhaul Hours is added to Depot manhours and the Organizational hours are incremented by 10 for engine packing purposes. Additionally, the cost of transporting the engine is summed to the total transportation costs. An engine repair is then scheduled for completion in a matter of days as defined by first the Engine Transport Time input parameter x 2 + Overseas Transport Time, if necessary, and Engine Depot Time which is input as a system parameter value. A spare check is then performed and finally the activity is transferred to Check LRU for LRU failure checks.

LRU Caused

This simulates the maintenance activity if an engine is removed and the failure is subsequently found to be due to

LRU malfunction. An accounting is made of the type of removal and 46 hours are added to intermediate hours for the removal and replacement of the LRU(s). An engine repair is scheduled for completion in 15 days and a spare check of engines is performed. Once these are completed, action is transferred to Check LRU.

SRU Caused

This indicates an engine removal was due to an SRU failure. The type of failure is increased by one and an engine repair is scheduled for completion in ngine Base Repair Time days, a value which is input in the first data set. A spares check for engine is then accomplished. The next step is to determine whether the SRU will be repaired at depot or intermediate level. This is done by use of a random number comparison to a value calculated as follows:

SI.TOT = Total of all SRU intermediate maintenance actions

SD.TOT = Total of all SRU depot maintenance actions

SI.PER = The value against which the comparison is made

$$\text{Where SI.PER} = \text{SI.TOT} / (\text{SI.TOT} + \text{SD.TOT})$$

Thus the percentage of intermediate actions is the decision factor. If the random number is less then the SI.PER value, the repair is to be done at the intermediate level and action is transferred to IREPAIR of SRU otherwise action is transferred to Depot Repair of SRU. Regardless of which subunit

action is transferred, the logic is the same.

IRepair or Depot Repair

In both of these possibilities, the type of failure is incremented and transportation costs are assessed. At this point, each SRU is checked for failure by use of a random number compared to each SRUs failure probability. Manhours associated with each failure are accounted for and a repair is scheduled. The repair time for each is dictated by either the parameter value SRU Base Repair Time for intermediate repair or the following equation for depot repair:

$$\begin{array}{c}\text{Transport}\\\text{Time}\\\text{Overseas}\end{array} + \begin{array}{c}\text{SRU Trans-}\\\text{port Time}\\\text{to Depot}\end{array} + \begin{array}{c}\text{SRU}\\\text{Depot}\\\text{Time}\end{array} + \begin{array}{c}\text{SRU Trans-}\\\text{port Time}\\\text{from Depot}\end{array}$$

Each of the above values are input as system parameters. In either case, a spare check is accomplished and activity is then transferred to Check LRU.

Check LRU

In this activity each LRU is checked for a failure. This is done by comparison of a random number to the individual LRU failure probabilities. Each LRU failure probability is determined by the following equation:

$$\text{LRU.PROB} = \left(\begin{array}{c}\text{Projected}\\\text{Maintenance}\\\text{Actions}\end{array} * \begin{array}{c}\text{Total}\\\text{Engines}\\\text{per A/C}\end{array} * \begin{array}{c}\text{Inspection}\\\text{Frequency}\end{array} \right) \Big/ 1000$$

If the random number is less than LRU.PROB, the LRU is considered failed and the appropriate repair hours are assigned. A depot repair for each LRU is scheduled in accordance with the following formula:

Overseas Transport Time	+	LRU Depot Transport Time	+	LRU Depot Repair Time	+	LRU Depot Transport Time

Each of these are values input into the system parameters. The final step in the inspection event is to schedule another inspection.

Event Intermediate Repair and Event Depot Repair

In these events a random number is generated and compared to an input condemnation factor. If the random number is less than the condemnation factor the part is condemned, accounted for and passess out of the system. Otherwise it is repaired and is returned to the spares pool by incrementing the appropriate level value by one.

Event Engine Repair

In this event the level (50) or engine spares pool is incremented by one and the action is completed.

Event TCTO

In this type of maintenance action the type of engine removal is accounted for and an engine repair is scheduled in seven days. A spare check is then performed to assess the spares pool level for engines. The last event to be considered is the scheduling of TCTOs.

Event Schedule TCTO

In this activity all the TCTO compliances for a particular TCTO are scheduled. Each engine that will not be removed during the coming year will be scheduled for a compliance point. This is done by forecasting the total engine

removals for the next 12 months and requiring all engines, save those to be removed to be complied with by separate engine removals. The last step is to schedule the next scheduling of a TCTO in [(365) * (Years between TCTOs)] days.

While some of the points made in this appendix may seem redundant with Chapter 3, it is the intent of this section to bring a more indepth look at the model logic for the interested reader.

APPENDIX F

USER'S MANUAL
LONG TERM WARRANTY
ANALYSIS VERSION
(WARR.3)

Purpose: To evaluate warranty packages over the life cycle of the engine system.

Alternate Uses: O&S Cost Studies
Project Base/Depot Workloads
Determine Parts Requirements
Sensitivity Analysis

Description: The WARR.3 model is a Monte Carlo type simulation model. It is written in Simscript II.5 and designed for usage on the Create computer system.

Files: Input Data Files - TEST100
- TEST.DAT
Source Program - WARR.3

This manual is designed to be used with the User's Manual for the SHORT.3 version. The intent of this version is to compare the expected improvement resulting from a warranty application to the expected results without those assurances. The following procedures will assist in accomplishing the desired analysis.

Step 1 - As in the SHORT.3 procedure, create the two data files using the same instructions with 2 exceptions.

a) Change the name of the "SHORT" file to "TEST100".

b) Add the variables "SIM" and "ST" to the end of the seventh line of data.

(i.e. MO.QUIT, SEED, SED, SIM, ST)

The added variables are used to initialize the simulation number and stopping point. The normal setting for 10 simulation runs is SIM = 1 and ST = 11. However, up to 30 total runs can be made by adjusting the SIM and ST levels up. However, due to time constraints on the Create system making

more than 10 runs at one time is not recommended.

Step 2 - With the data files constructed it is possible to run the simulation. The simulation should be made first with the warranty option including the expected improvements and warranty costs. The data sets can then be reset to show the non-warranty conditions and the simulation is performed again.

Due to the size of these two projects they will require overnight running. In the morning results can be collected at the central site. Since there is no automation of data handling beyond this point, the yearly accumulated totals for all 10 runs of each option should be averaged and the average lines plotted. This plot of accumulated cost versus time will provide the breakeven point. Further testing can be done using an SPSS F test to determine when the two lines are no longer significantly different. However, this technology has not been built in and is left to the analyst.

APPENDIX G

USER'S MANUAL
SHORT TERM WARRANTY
ANALYSIS VERSION
(SHORT.3)

Purpose: To evaluate warranty packages effective for short periods of time.

Alternate Usage: Operation and Support Cost Studies
Project Base/Depot Workloads
Determine Parts Requirements
Sensitivity Analysis

Description: The SHORT.3 model is a Monte Carlo type simulation model. It is written in Simscript II.5 and designed for usage on the Create computer system.

Files: Input Data Files - SHORT
- TEST.DAT
Source Program - SHORT.3

This manual is intended to illustrate the commands necessary to perform the computer operations to execute the SHORT.3 simulation program. Words underlined indicate a response by the operator and CR indicates a carriage return.

To Start

Log on the Create Computer System

STATION ID - XY CR (Terminal Identifier)

USER ID - 82X111 CR

PASSWORD - LL11 CR

PROBLEM NO. - WP0000 CR

SYSTEM?

The user is now ready to build the 2 data files necessary for input to the SHORT.3 model. The first data file will contain engine parameters, cost data, pipeline assumptions, delivery schedule and basing concept. The second data file will contain SRU and LRU reliability and maintainability data. The following data file examples will assist the user in

constructing his or her own. The entries indicate the input variable.

Building SHORT Data File

```
SYSTEM?  Editor CR

OLD OR NEW?  New CR
ENTER
*75#DATE(1)  DATE(2) CR
*76#PRGM  ECNT  SVR  ENG.COST  RFAC  OVER.PER  WARR CR
*77#SE.COST(1)  SE.COST(2)  SE.COST(3)  WARR.COST CR
*78#FHP  INFREQ  IMAN  ORATE  IRATE  DRATE  EOH.HRS CR
*79#TE  TL  TS  EDTIME  EBTIME  SDTIME  SBTIME  LDTIME CR
*80#ETCOST  STCOST  LTCOST  INFLAT  DISC CR
*81#YR.START  YR.REPORT  YR.TCTO  MO.QUIT  SEED  SED CR
*82#EFAIL(1)  EFAIL(2)  EFAIL(3) CR
*83#MAX CR
*84#PQ(1)  PQ(2) ... PQ(MAX) CR
*85#NO.OF.BASES CR
*86#BASEQTY(1) ... BASEQTY(NO.OF.BASES) CR
*87#CIRF CR
     CR
-  SAVE SHORT CR
   DATA FILE   SHORT   SAVED
-  DONE CR
SYSTEM?  Editor CR
OLD or NEW?  New CR
ENTER
*300#SCNT CR
*310#NAME(1) NAME(2) SIRATE SRU.HRS(1,1) SRU.HRS(2,1)
     SPRATE SRU.HRS(3,1) SRU.HRS(4,1) SCOST(1) CON.FAC(1)
     CR
*320#... CR          ALL SRU DATA IDENTICAL
     ...
*450#LCNT CR
*460#NAME(1) NAME(2) LRATE LRU.HRS(1,1) LRU.HRS(2,1)
     LRU.HRS(3,1) LCOST(1) CON.FAC (1+SCNT) CR
*470# ... CR          ALL LRU DATA IDENTICAL
     ...
*550# CR
-  SAVE TEST.DAT CR
   DATA FILE   TEST.DAT   SAVED
-  DONE CR

SYSTEM?
```

At this point, the user is ready to run the SHORT.3 simulation model. To do this follow the procedure below.

```
SYSTEM?  CARD CR
OLD or NEW?  OLD SHORT.3 CR
*READY
*RUN CR
*SNUMB  E002T
```

E002T is the system identifier for the run. This allows the user to check the status of the run. Status checks are accomplished as follows:

```
*JSTS  E002T  CR
*E002T EXECUTING
```

25 minutes to 1 hour later

```
*JSTS  E002T  CR
*E002T OUTPUT WAITING ID=XY
 Normal Termination
```

Output can now be obtained as follows:

```
*LINE LENGTH 132 CR
*JOUT  E002T CR
FUNCTION?  Activity 2 CR
FUNCTION?  EPRINT 06 CR
                 .
                 .
                 .
          Model Output

*END OF 06
FUNCTION?
```

Before exiting the JOUT system, the user should release the job by the following actions.

```
FUNCTION?  Release CR
SYSTEM?    Bye CR
```

APPENDIX H

SPSS ANALYSIS PROGRAMS

The Statistical Package for the Social Sciences (SPSS) is a canned set of analytic processes used for routine data analysis.

This appendix contains all SPSS programs used in the analysis of data in this research effort. The programs shown here are written for use on the AFIT Harris system.

```
1 8SPSS*SPSS8
2 RUN NAME        ONEWAY ANOVA FOR VALIDATION
3 PRINT BACK      CONTROL
4 VARIABLE LIST   GROUPS,OUTPUT
5 INPUT FORMAT    FREEFIELD
6 N OF CASES      UNKNOWN
7 ONEWAY          OUTPUT BY GROUPS(1,2)
8 STATISTICS      ALL
9 READ INPUT DATA
```

```
1 8SPSS*SPSS8
2 RUN NAME        LILLIEFORS TEST FOR NORMALITY
3 PRINT BACK      CONTROL
4 VARIABLE LIST   OUTPUT
5 INPUT FORMAT    FREEFIELD
6 N OF CASES      UNKNOWN
7 NPAR TESTS      K-S(NORMAL)=OUTPUT
8 STATISTICS      ALL
9 READ INPUT DATA
```

```
8SPSS*SPSS8
RUN NAME         TWO WAY ANALYSIS  OF VARIANCE
PRINT BACK       CONTROL
VARIABLE LIST    ENG,SVR.COST
INPUT FORMAT     FREEFIELD
N OF CASES       UNKNOWN
ANOVA        .   COST BY ENG(1,3) SVR(1,3)
STATISTICS       ALL
READ INPUT DATA
```

```
8SPSS*SPSS8
RUN NAME         ONEWAY ANOVA FOR ENGINE COST
PRINT BACK       CONTROL
VARIABLE LIST    ENG,SVR.COST
INPUT FORMAT     FREEFIELD
N OF CASES       UNKNOWN
*SELECT IF       (SVR EQ 2)
ONEWAY           COST BY ENG(1,3)
                 RANGES = DUNCAN(.10)
STATISTICS        ALL
READ INPUT DATA
```

```
8SPSS*SPSS8
RUN NAME         ONE WAY ANOVA FOR SHOP VISIT RATE
PRINT BACK       CONTROL
VARIABLE LIST    ENG,SVR,COST
INPUT FORMAT     FREEFIELD
N OF CASES       UNKNOWN
SELECT IF        (ENG EQ 2)
ONEWAY           COST BY SVR(1,3)
                 RANGES = DUNCAN(.10)
STATISTICS        ALL
READ INPUT DATA
```

APPENDIX I

BMDP ANALYSIS PROGRAM

The Biomedical Data Package is a canned set of analytic processes used for biomedically oriented data analysis.

This appendix contains the BMDP program used to generate the normality plots presented in the text. The program shown was altered only slightly by changing the year input and the data sets in order to plot the four sets of data. This program is designed for use on the ASD CYBER System with interface through the AFIT Harris System.

```
JOB GHT SYST BCDDMP PRI=15 OUT=0
*RJE 100 GHT *
GHT,CM100000.  T790704,HELLESTO
ATTACH,BMDP5D,ID=BMDP,SN=ASDAD.
BMDP5D.
/*EOR
/PROBLEM       TITLE IS '2004'.
/INPUT         VARIABLE IS 1.
               FORMAT IS '(F6.2)'.
/VARIABLE      NAMES IS COST.
/PLOT          TYPES ARE NORM.
/END
```

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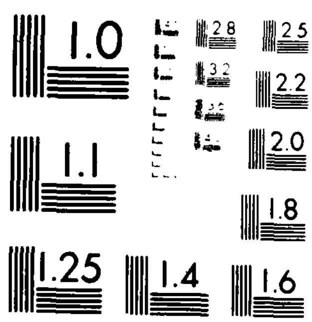

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